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BRONCHOSPIROMETRIC STUDIES DURING THORACIC SURGERY

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INTRODUCTION

PREVIOUS studies from this laboratory have confirmed the frequent development of severe acidosis during intrathoracic surgery performed under general anesthesia.[1, 2] This acidosis is respiratory in nature due to inadequate alveolar ventilation despite the maintenance of a minute volume of ventilation in excess of that found preoperatively. No objective information, however, has been available on the relative contributions of the two lungs during controlled respiration in thoracic surgery. Through an adaptation of bronchospirometric techniques, it was possible to measure ventilation and also carbon dioxide output of each lung throughout thoracic surgical procedures.

METHODS AND MATERIALS

The Carlens bronchospirometry catheter was used in place of the usual endotracheal tube in order to separate the ventilatory flow of the two lungs.[3] The catheter was inserted immediately following induction of anesthesia. The proper placing of the catheter was easily checked by auscultation during ventilation of each lung separately. Auscultation over the anterior upper left chest area assured that the catheter had not been inserted beyond the orifice of the left upper lobe bronchus. The pilot balloons served as a constant check on the adequate inflation of the tracheal and bronchial balloons, thus assuring against leaks.

The general principles and techniques of measuring ventilation during surgery have been described previously.[1] Fig. 1 illustrates the method used to record total ventilation and to obtain expired air samples. The expired air from each side was measured by separate volume displacement gas meters, the accuracy of which was determined to be within 1 per cent. Two liter mixing chambers were inserted in the expiratory arm of each circuit. A sparkless electric fan in each chamber assured adequate mixing of gas samples.

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The expired air from each circuit was returned to the anesthesia machine after passing through the mixing chamber and volume meter. Ventilation was recorded at five-minute intervals. Expired air samples were collected every thirty or sixty minutes. Arterial blood samples were obtained through a sterile polyethylene tube placed in the brachial artery. These were drawn

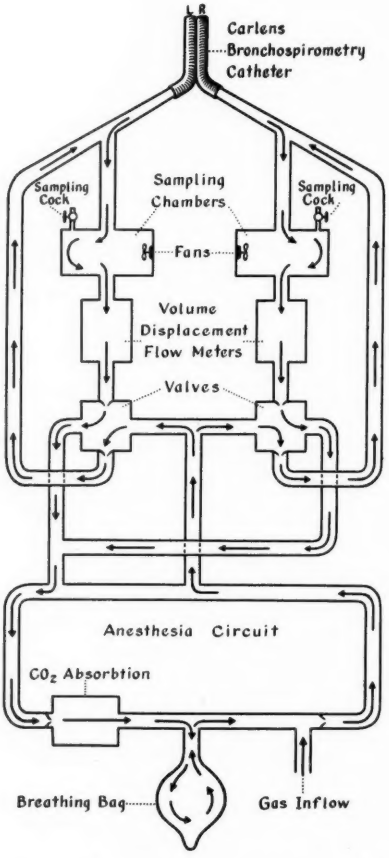

Fig. 1.—Diagram of anesthesia and metering-sampling circuits used.

simultaneously with the collection of expired air samples. The carbon dioxide concentration in the expired air was determined by standard Haldane techniques. A pH determination of whole blood was made in a glass electrode using a Cambridge potentiometer as described by Wilson.[4] Arterial blood carbon dioxide content was measured by the method of Van Slyke and Sendroy.[5] Carbon dioxide tension of arterial blood was calculated from the pH and carbon dioxide content of arterial blood using the nomogram pre-

pared by Singer and Hastings.[6] Alveolar and dead space ventilation for both lungs together can be determined from the above information as described previously.[7]

Ten patients (24 to 61 years of age) were studied during intrathoracic surgery. Table I lists the diagnosis, the degree of pulmonary resection, and an estimation of the disease in the contralateral lung. The extent of pulmonary resection varied from only a biopsy to lobectomy. Anesthesia consisted of intravenous Pentothal sodium and curare supplemented with nitrous oxide. Manually controlled positive pressure respiration was practiced throughout the operative period. All of the patients except one were operated upon in the semilateral thoracotomy position. H. W. was operated on in a full lateral position. The values indicated as prethoracotomy were obtained after the patient had been positioned on the operating table but before the chest had been opened.

TABLE I. CLINICAL DATA

PATIENT	AGE	SURGICAL PROCEDURE	DIAGNOSIS	CONTRALATERAL DISEASE
W. S.	24	RUL nodulectomy	Pulmonary tuberculosis	Left thoracotomy with subsegmental resection and wedges LUL done 2 months previously
H. C.	46	Subsegmental RUL	Pulmonary tuberculosis	None
G. F.	30	RUL lobectomy	Pulmonary tuberculosis	Minimal fibrosis, left apex
J. B.	29	Resection of segments left 7, 8, 9, 4, 5	Bronchiectasis	None
H. W.	51	Exploration and biopsy (not resectable) left	Bronchiogenic carcinoma	Multiple small calcifications throughout both lung fields
A. S.	26	RUL lobectomy	Pulmonary tuberculosis	Fibronodular infiltrate, left 2nd interspace
K. N.	30	Subsegmental LUL, Segmental B6	Pulmonary tuberculosis	Subsegmental resection and nodulectomies, right
D. S.	33	Subsegmental nodulectomy RUL	Pulmonary tuberculosis	Dense infiltrate left apex
A. G.	61	Two subsegmental resections and nodulectomy RUL	Pulmonary tuberculosis	None
C. G.	47	Segmental 1, wedge 2, RUL	Pulmonary tuberculosis	Fibronodular infiltrate, left apex

RUL = Right upper lobe.
LUL = Left upper lobe.

RESULTS

Table II, A gives the values for total ventilation, per cent of total ventilation contributed by the operated lung, total carbon dioxide excretion, and per cent of carbon dioxide output by the operated lung prior to and at varying time intervals following opening of the chest in each of the ten patients. Table II, B and C, gives the arterial pH, arterial carbon dioxide tension, calculated alveolar ventilation and dead space ventilation values found in four patients.

Fig. 2 presents the mean values for total ventilation, per cent of ventilation contributed by the operated lung and per cent of carbon dioxide excretion by the operated lung prior to and at time intervals following opening of the chest.

TABLE II

PATIENT	PRE-THOR.	½ HR.	1 HR.	2 HR.	3 HR.	PRE-THOR.	½ HR.	1 HR.	2 HR.	3 HR.	PRE-THOR.	½ HR.	1 HR.	2 HR.	3 HR.	PRE-THOR.	½ HR.	1 HR	2 HR.	3 HR.
	A. Ventilatory Studies																			
	Total Minute Ventilation ($\dot{V}$) liters/min. STPD					Per cent $\dot{V}$ by Operated Lung					Total Minute CO_2 Output ($\dot{V}_{CO_2}$) ml./min. STPD					Per cent $\dot{V}_{CO_2}$ by Operated Lung				
W. S.	14.4		22.90	17.74		53.5		49.6	49.3		345.0		449.7	408.4		56.7		37.7	46.0	
H. C.	12.87	12.27	16.00	9.91		55.3	47.2	44.4	49.4		391.0	304.5	443.7	272.8		59.7	39.3	36.8	44.7	
G. F.	11.26	11.42	11.62	11.10	10.80	54.7	45.8	46.0	54.6	53.7	406.1	385.1	406.3	357.3	493.7	60.1	41.2	41.3	57.8	37.4
J. B.	14.20	11.32	23.53	14.78	10.52	48.3	45.8	40.8	36.0	36.4	334.2	300.8	754.0	427.8	404.1	49.3	31.9	19.1	17.3	24.3
H. W.	9.21	12.26	9.77			50.1	40.4	41.3			285.5	387.7	269.8			46.6	33.5	33.6		
A. S.	9.21	11.79	12.29	13.04	14.08	53.9	49.4	51.5	47.7	48.8	253.3	470.3	405.9	561.7	594.8	57.4	45.3	44.4	44.7	41.2
K. N.	8.52	6.36	7.92		14.01	49.8	47.2	44.4		50.6	238.5	179.7	203.7		339.6	49.8	42.4	40.6		49.1
D. S.	12.35	15.42	14.33	12.73		55.2	51.7	45.8	44.1		255.4	329.5	338.4	422.6		55.5	49.1	39.2	38.5	
A. G.	11.18	9.57		12.16	11.72	55.8	52.3		54.2	52.9	275.7	260.6		419.4	567.8	61.1	49.3		57.4	46.9
C. G.	4.77	8.70	7.98	18.52	12.09	58.9	46.8	51.5	58.5	48.5	156.3	405.3	337.4	641.5	458.5	63.6	43.5	52.8	58.4	47.3
Mean	10.80	11.01	14.04	13.75	12.20	53.55	47.40	46.14	49.23	48.48	294.1	335.94	400.99	438.94	476.42	55.98	41.72	38.39	45.6	41.03
S. D.	2.95	2.56	5.85	3.06	1.54	3.24	3.55	3.99	7.00	6.28	75.8	86.8	155.3	114.7	96.9	5.66	6.10	9.05	13.65	9.3
	B. Arterial Blood Studies																			
	Arterial pH (pH_a)					Arterial CO_2 tension (Pa_{CO_2}) mm./Hg					Arterial CO_2 content (Ca_{CO_2}) mM/liter									
H. C.	7.28	7.22	7.29	7.26		54.0	61.0	46.0	52.0		22.71	22.64	19.55	20.57						
G. F.	7.24	7.20	7.17	7.21	7.24	60.0	62.8	70.3	61.0	57.7	22.58	21.89	23.06	21.71	21.44					
J. B.	7.34	7.23	7.23	7.29	7.29	45.8	61.5	60.5	56.0	53.5	21.20	22.95	22.88	23.64	22.37					
C. G.	7.42	7.14	7.10	7.34		35.3	74.1	84.9	47.8		19.43	22.65	23.66	21.16						
	C. Calculated Ventilatory Values																			
	Alveolar Ventilation ($\dot{V}_A$) L./min.					Dead Space Ventilation ($\dot{V}_D$) L./min.					$\dot{V}_D/\dot{V} \times 100$ (%)									
H. C.	4.90	3.38	6.53	3.55		7.97	8.89	9.47	6.36		61.9	72.4	59.2	64.2						
G. F.	4.69	4.25	4.01	4.06	5.93	6.57	7.17	7.61	7.04	4.87	58.3	62.8	65.5	63.4	45.1					
J. B.	5.00	3.35	8.54	5.23	5.17	9.20	7.97	14.99	9.55	5.35	64.8	70.4	63.7	64.6	50.9					
C. G.	3.07	3.79	2.76	9.31		1.70	4.91	5.22	9.21		35.6	56.4	65.4	49.7						

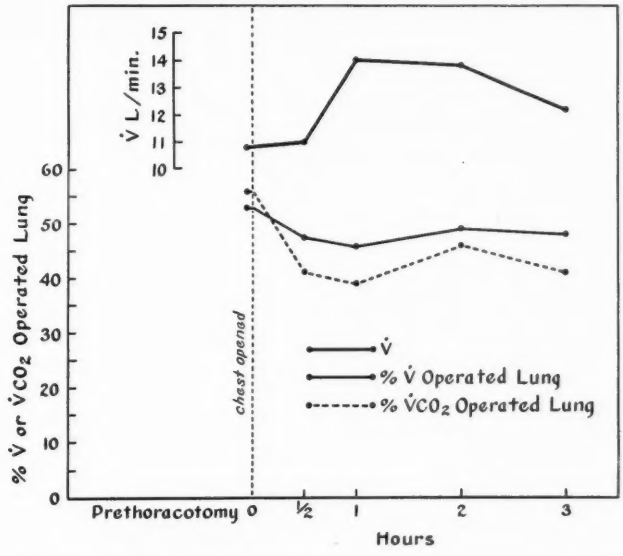

Fig. 2.—Mean values found in ten patients for total ventilation ($\dot{V}$), per cent of total ventilation by the operated lung (% $\dot{V}$), and per cent of total carbon dioxide excretion by the operated lung ($\dot{V}co_2$) prior to and at time intervals following opening of the chest.

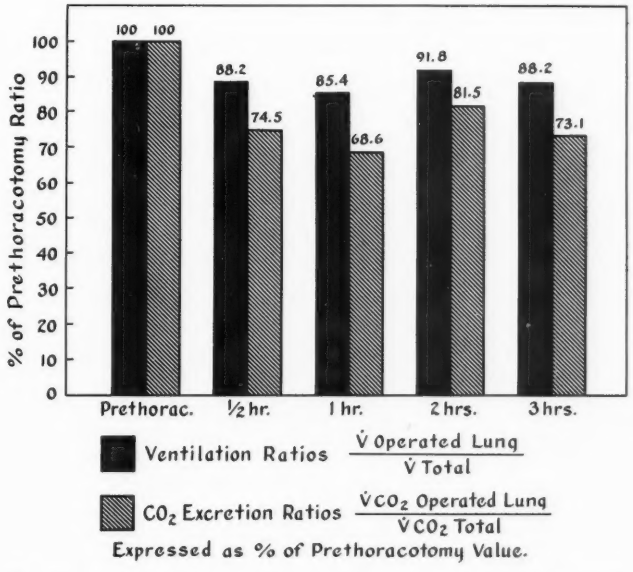

Fig. 3.—Ventilation ($\dot{V}$) and carbon dioxide excretion ($\dot{V}co_2$) ratios expressed in per cent of prethoracotomy values at time intervals following the opening of the chest.

Fig. 3 gives the mean ventilation and carbon dioxide excretion ratios expressed in per cent of prethoracotomy values at time intervals following opening of the chest.

A decrease in the proportion of ventilation and of carbon dioxide excretion by the operated lung occurred in all ten patients following opening of the chest. This decrease persisted throughout the procedure.

The decrease in the proportion of carbon dioxide excretion by the operated lung following the opening of the thorax was consistently greater than the decrease in the ventilation ratio during this period (Table II, A and Figs. 2 and 3).

Some of the patients had total carbon dioxide excretion values, following opening of the chest, considerably greater than that found prior to thoracotomy. This rise was not noted in earlier studies.[1]

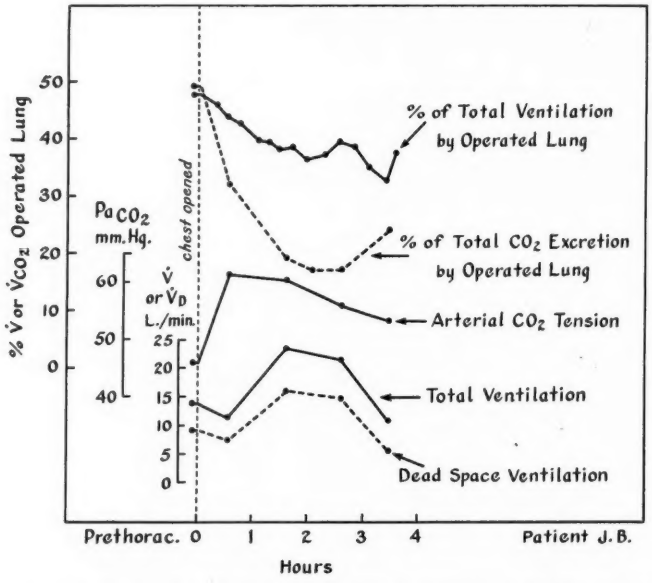

Fig. 4.—Values of per cent of total ventilation contributed by the operated lung, per cent of carbon dioxide excretion by the operated lung, arterial carbon dioxide tension, total ventilation and dead space ventilation at time intervals in patient J. B. Resection of basal segments and lingula was performed for bronchiectasis.

The four patients in whom blood studies were made revealed a usual increase in dead space ventilation following opening of the chest. The decrease in alveolar ventilation following opening of the chest was not as consistent as was found previously.[1]

Patient J. B. (Fig. 4) showed a moderate fall in proportion of ventilation contributed by the operated lung following the opening of the chest which was accompanied by a marked fall in the proportion of carbon dioxide excretion

by that lung. The alveolar ventilation was not increased sufficiently to maintain a normal arterial carbon dioxide tension in the presence of an increased production of carbon dioxide even though the total ventilation increased up to 23.5 liters per minute. Most of the ventilation at these relatively high minute volumes consisted of dead space ventilation.

DISCUSSION

The changes noted in ventilation must be considered in the light of the anesthetic techniques applied. The combination of Pentothal sodium and curare virtually eliminates any ventilation by the patient himself. Therefore, in our patients, ventilation was produced by means of positive pressure inspiration and passive expiration. Our data cannot be applied to systems employing unassisted or partially assisted respiration.

The decrease in proportion of ventilation performed by the operated lung during thoracotomy could be due to a decrease in ventilation of the operated lung, an increase in ventilation of the unoperated lung, or both. A decrease in ventilation of the operated lung may, in part, be related to manipulation and limitation in expansion of the lung by the surgeon. Areas of atelectasis and partial or complete bronchial obstruction could change the physical characteristics of the lung enough to affect ventilation. Clamping and resection of pulmonary tissue must play a role, although patient H. W., in whom only a small biopsy was done, demonstrates that this cannot be the only factor since he showed changes similar to those patients undergoing more extensive pulmonary resection. Increased ventilation of the unoperated lung could occur if the characteristics of the closed chest side were altered by mediastinal mobility and by curarization of the chest wall muscles to permit greater ventilation with the same level of applied pressure.

The only data presented of individual lung function are ventilation and carbon dioxide excretion. More important physiologic measurements of the individual lungs would be alveolar ventilation and dead space ventilation. The latter simply represents the difference between alveolar ventilation and total ventilation. Accurate alveolar carbon dioxide tensions must be known, however, to determine the alveolar ventilation of a lung. The determination of these more important physiologic measurements must await the development of newer techniques applicable during surgery. Our data do not allow an estimation of alveolar ventilation of the individual lung. The proportion of alveolar ventilation assumed by the operated lung would fall to a greater extent than the fall in ventilation ratio if the dead space ventilation of each lung remained the same, changed proportionately, or if the dead space in the operated lung increased more than in the unoperated lung. Only if there were a greater increase of dead space ventilation by the contralateral lung than by the operated lung could there be an equal or lesser fall of the alveolar ventilation ratio than of the total ventilation ratio. It is highly improbable, however, that the latter would occur.

Carbon dioxide output of each lung is a complex function of alveolar ventilation, blood flow, venous carbon dioxide tension, and inspired carbon

dioxide tension. Alveolar ventilation is relatively the most important factor determining carbon dioxide excretion within usual physiologic ranges. The finding of a greater decrease in carbon dioxide output ratios than in ventilation ratios is consistent with the described greater relative decrease in alveolar ventilation. Variations in dead space ventilation and in pulmonary blood flow may well have occurred in one or both lungs, but one need not assume changes in these factors to explain the alteration observed in carbon dioxide output ratios.

The application of the presented data to clinical situations must be made with caution. It is clear, however, that the contralateral lung must assume a greater proportion of respiration during thoracotomy done under Pentothal sodium curare anesthesia and manual positive pressure ventilation than it does prior to surgery. It follows that the function of the unoperated lung must be sufficient to meet this increased demand, or accumulation of carbon dioxide will occur. In most cases the operated lung did contribute substantially to ventilation and carbon dioxide output.

SUMMARY AND CONCLUSIONS

1. Differential lung ventilation and carbon dioxide excretion have been measured in ten patients undergoing resectional pulmonary surgery performed under Pentothal sodium curare anesthesia with manually controlled positive pressure respiration. Four of the patients had concomitant determinations of arterial pH, arterial carbon dioxide content and calculation of arterial carbon dioxide tension, total alveolar ventilation, and total dead space ventilation.

2. A consistent decrease was present in the proportions of ventilation and of carbon dioxide excretion performed by the operated lung during thoracotomy.

3. The proportion of the carbon dioxide output performed by the operated lung consistently fell to a greater extent during thoracotomy than did the proportion of ventilation.

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RESECTION FAILURES IN PULMONARY TUBERCULOSIS

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PULMONARY resection has assumed a major role in the present treatment of tuberculosis. The indications enunciated by early pioneer centers[1-5] were quite readily accepted. These included failure of thoracoplasty and pneumothorax treatment, unilateral destroyed lung, bronchostenosis, empyema with parenchymal disease, tuberculoma, and blocked cavity. The addition of more effective antibiotic therapy, however, and a more aggressive attitude toward caseous residua have increased differences of opinion regarding indications. As a background for analysis of the present resection program employing current concepts of therapy, a study of the reasons for failure of a surgical group prior to the use of long-term drugs was undertaken. This study embraces the period from June 4, 1946, through Sept. 17, 1951, during which time 400 patients had resections for pulmonary tuberculosis. It thereby affords observation of all patients for a period longer than two years. Failure of resection has resulted in early death (surgical mortality), late death (after six weeks), readmission to hospital due to exacerbation or reactivation, multiple resection, and other failures because of continuation of positive sputum or changing x-ray. An outline of the resection program and a summary of end results as derived from follow-up examination also are presented.

The history of the resection program is graphically illustrated by Figs. 1 and 2. Beginning in June, 1946, major resections were used in increasing incidence, reaching a peak in 1950, declining in 1951 and 1952, to regain new impetus during 1953. The initial trend culminating in the first "high" in 1950 reflects the changing policy in the indication for pulmonary resection versus thoracoplasty. The second peak in 1953 follows the advent of long-term antibiotic therapy and reflects the increasing incidence of segmental and localized resection.

Within the period of this study, streptomycin and para-aminosalicylic acid came into general use. The first 38 patients were operated upon without benefit of these drugs. The remaining 362 all received antibiotics. Usually 1 Gm. of streptomycin was given daily from one to fourteen days before surgery and from two to six weeks thereafter. A few patients with acute and very extensive disease were treated more vigorously and for a longer time. Prior to surgery the average patient was treated with a conservative and

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prolonged period of bed rest. Following resection (except for brief postoperative ambulation) bed rest prevailed for a minimum of six months, followed by graduated exercise. This program usually resulted in discharge of the patient about one year after surgery.

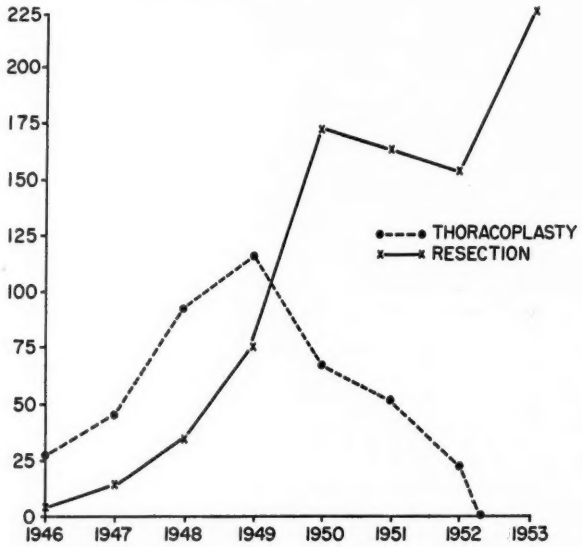

Fig. 1.—Annual incidence of thoracoplasty and resection.

In general the character of the lesions in cases coming to surgery after therapy with bed rest and short-term drugs has differed widely from that seen at the present time with use of long-term drugs. Greater problems were encountered technically. In some cases the finding of unsuspected disease in a lung resulted in pneumonectomy rather than lobectomy. In other instances, pneumonectomy was forced due to vascular difficulties during surgery. In many cases, for fear of reactivation, masses of functioning lung were removed in order to eliminate scattered foci of caseous disease. At present these lesions would be resected locally with minimal sacrifice of functioning lung, or long-term drugs would be used to complete their healing.

SELECTION OF PATIENTS

Patients are selected for surgery by a majority vote of the Staff, meeting weekly in general conference. The pertinent data and x-rays are presented by the physician in immediate charge of the patient; full discussion ensues, and opinions are expressed before a vote is taken. For the indication and the type of surgery to be done, laminographic x-ray study has been employed extensively and reliably. Similarly, with the inauguration in 1948 of facilities for the adequate study of pulmonary function, decisions for or against surgery have been influenced by the findings of the pulmonary physiologists.

TYPE OF SURGERY

During the period of this analysis, there were 411 resection procedures on 400 patients as performed by the three consultant thoracic surgeons of Firland Sanatorium* and by the surgical residents under their supervision. The resection procedures include 160 pneumonectomies, 244 lobectomies, six segmental resections, and one nodulectomy. A high percentage of the pneumonectomies and lobectomies followed unsuccessful thoracoplasty procedures. Segmental resection was not done extensively, a reflection of the opinion that removal of all significant areas of caseation by more extensive resection protected the patient against reactivation, whereas cutting through disease was dangerous. Thus, at times, considerable functional lung tissue was sacrificed.

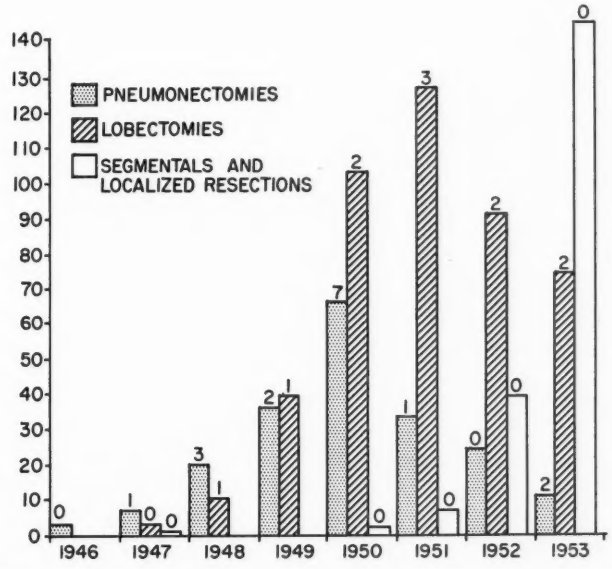

Fig. 2.—Types of resection. The number of surgical deaths for each type and year is indicated by the number above each column.

SURGICAL MORTALITY

Twenty-one patients died within six weeks of surgery, an arbitrary interval accepted by most surgeons in computing surgical mortality. In addition, some of our late deaths were directly accountable to surgical complications. The over-all surgical mortality of the 411 patients was 5.1 per cent. Fourteen deaths occurred following pneumonectomy, a mortality rate of 8.7 per cent. The relatively large number of pneumonectomies, in itself, indicates the severity of the disease process and the greater likelihood of in-

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volvement of other systems or the opposite lung. Seven deaths followed lobectomies, a mortality of 2.9 per cent. There were no deaths in the segmental or localized resections.*

Examination of the protocols of the patients dying in the early postoperative period makes it apparent that a most important factor accounting for failure was inadequate functional reserve. It is emphasized that the functional insufficiency of these patients was observed clinically by studying their behavior during and following surgery. Complications in the nature of retained secretions, paradoxical respiration, delayed expansion through temporary surface leakage of air, phrenic and recurrent laryngeal nerve paralysis, successfully weathered by patients with greater reserve, have in these patients been fatal. Three patients in this group presented insurmountable respiratory difficulties under anesthesia. This resulted in prolonged anoxia with respiratory failure in the immediate postoperative period.

Major surgical accidents accounted for four deaths. Two of these occurred during extrapleural pneumonectomy; in one an infected oleothorax and bronchopleural fistula, and in the second a two-stage unsuccessful thoracoplasty complicated by empyema, were surgical exercises of major magnitude. A third patient died on the operating table during closure of the skin when the ligature on the pulmonary artery gave way. The fourth died of hemorrhage from the chest wall following thoracoplasty three weeks after pneumonectomy. Major blowout of a bronchial stump has been responsible for early death only twice. Pulmonary embolism causing death was proved in two cases, suspected in two others.

LATE DEATHS

The number of patients dying six weeks or later postoperatively was greater than the number succumbing in the early postoperative period: 33 late, 21 early. These complications for the most part are directly related to the surgery, although 11 patients succumbed during the second, 7 during the third, and 2 during the fourth year. Empyema with bronchopleural fistula accounted for a third of these late deaths. Two patients had difficult extrapleural pneumonectomies with areas of caseation encountered during surgery, a factor frequently resulting in empyema. In one patient an empyema was demonstrated by needle aspiration eight months after surgery. She died eight days later from disturbance of cardiac conduction mechanism, probably ventricular fibrillation. Autopsy revealed no fistula. The remaining seven patients were found to have a co-existent empyema and bronchopleural fistula.

Functional inadequacy finds its late expression in cardiac death. Nine patients, including two listed by the coroner without autopsy as "coronary occlusion and sclerosis" and "acute cardiac insufficiency, chronic valvular heart disease" died late cardiac deaths. It seems probable that this group

*Two hundred and sixteen localized resections have been performed prior to April 1, 1951, with no deaths.

developed cardiac strain due to inadequate pulmonary functional reserve. Other late deaths include five patients who expired from progressive disease. As an indication of the severity of the disease, four required pneumonectomy. Nine other patients died of indirect or unrelated causes.

READMISSIONS

Of primary interest are the 27 patients who had undergone resectional therapy and left the sanatorium, only to be readmitted for further treatment. Eighteen of these patients had been discharged with Staff approval. Two were given disciplinary discharges, and the remaining seven left the hospital against medical advice. Evidence of reactivation of disease was demonstrated either by change in x-ray shadow or by the discovery of positive sputum, or both. Fifteen (58 per cent) returned during the first two years after surgery, the greatest number reactivating during the second year. However, a significant number returned in the fourth, fifth, and sixth years (Table I). This contrasts with the series of segmental resections reported by Chamberlain and associates[6] in which late reactivations have not represented a serious problem. Two-thirds of the exacerbations in their series occurred within the first six months.

TABLE I. TIME OF POSTSURGICAL READMISSION

	NO. OF PATIENTS	
First year	3	58%
Second year	12	
Third year	5	
Fourth year	4	
Fifth year	2	
Sixth year	1	
Total	27	

Twelve of the readmitted cases had undergone pneumonectomy. This being a significantly high number relative to the lobectomy cases, it would seem again to reflect the greater severity of the original disease and probably the lesser resistance of the host. Of the 15 postlobectomy patients, the exacerbation occurred in the contralateral lung in six, in the operated lung in five, and in both lungs in two. Two patients showed no x-ray change and were readmitted for investigation of the source of a positive sputum culture. In one an ulceration of the stump was found. In the other, no source was determined. Both cleared with additional antibiotics. The efficacy of drug therapy is attested by the fact that it was possible to convert the sputum and ultimately discharge 16 of these patients on long-term antibiotics. Six of the readmission group remain as in patients but with a favorable outlook. One patient who had undergone pneumonectomy was recently readmitted with cavitary disease. Prognosis is guarded. Two remain outside the sanatorium with intermittently positive cultures without known source. One has died from unrelated causes, and one is not available for follow-up.

MULTIPLE RESECTIONS

Eighteen* of the series of 400 patients have undergone multiple resections, three as planned in their over-all therapy. Of the remaining 15 patients, 13 required a second resection because of recrudescence of disease postoperatively, one because of empyema, and one because of stump blowout. Increased disease, as seen by x-ray and by sputum studies, occurred from two to fifteen months following the initial surgery, with the average interval being eight months. We noted the extension of disease in the operated lung in ten of the thirteen cases, in both the operated lung and the contralateral lung in two cases, and in the contralateral lung alone in one instance. All of these patients received some form of short-term antibiotics postoperatively, consisting of daily streptomycin for a period of two to four weeks, some receiving PAS as well. Twelve patients were treated with streptomycin preoperatively for a short period.

Twelve of the eighteen patients ultimately achieved a good result following removal of more lung tissue. At the present time they are living and well with stable x-rays and negative sputum. Two remain as inpatients, one still has a positive sputum and a guarded prognosis under long-term drug therapy, the other is classed as chronic custodial. Two patients were discharged with advice, with negative sputum, but are lost to follow-up. Two are dead, one appearing with the early deaths and the second with the late deaths.

OTHER RESECTION FAILURES

Because of positive sputum or changing x-ray, 15 additional patients are also classified as failures. Five remain in the hospital.† They all have experienced extension of disease postoperatively and persist with positive sputum despite prolonged drug therapy. In four of the five, inadequate functional reserve has prohibited further surgical consideration. In fact, a study of their postoperative course suggests that borderline function complicated by sputum retention and paradoxical respirations probably played a large part in promoting the extension of their disease. In one, repeated exacerbation of sickle-cell anemia seemed directly related to the extension of her tuberculosis. Four other patients are at home. One has a low functional reserve with intermittently positive sputum, another has persistently positive sputum cultures without known source. A third is awaiting recheck studies, after an isolated positive sputum culture, and questionable x-ray changes. The fourth is being sought for readmission following the development of positive sputum and definite x-ray changes seven years after pneumonectomy. Five other patients with late isolated positive cultures and without x-ray changes are under observation. One patient with negative sputum is awaiting recheck after questionable x-ray change in the opposite lung.

*Eleven patients were operated upon a second time during the period of this study, thus accounting for the 411 resection procedures on 400 patients. The remaining seven had their second procedure subsequent to this study.

†Including the two of the multiple resection group, the persistent inpatients total seven.

SUMMARY OF RESULTS

We have been able to follow 357 of the 400 patients, 89 per cent. Table II shows the present status of the patients followed.* Seventy-eight per cent ultimately achieved a good result and are at home, sputum negative. The total death rate of the patients followed was 15 per cent; the surgical mortality 5.1 per cent. The results of other series as cited by Shabart and Samson,[7] to which we have added our own results for comparison, are shown in Table III.

TABLE II. PRESENT STATUS OF 357 PATIENTS FOLLOWED

At Home	Sputum negative		279	(78%)
At Home	Sputum positive		10	
	Isolated positive culture	5		
	Condition unsatisfactory (MHB)	4		
	? changing x-ray	1		
In Sanatorium			14	
	Readmitted	7		
	Persistent inpatients	7		
Dead			54	
	Early surgical deaths	21		
	Late deaths	33		

TABLE III. RESULTS OF PULMONARY RESECTION FOR TUBERCULOSIS

AUTHORS	NO.	WELL	SICK OR COMPLICATIONS	OPERATIVE DEATHS	TOTAL DEATHS
Gale, Sweet, Day, Chamberlain, Bailey, Himmelstein, Brantigan	745	496	95	47	137
(per cent)		66.5	12.6	6.3	18.3
Glover	347	242			
(per cent)		70	7.7		22
Davidson	200	151			
(per cent)		75.5	4.5		20
Overholt	426	302		38	87
(per cent)		70.9		8.9	20.4
Shabart, Samson	95	65	13	6	17
(per cent)		68	14	6	18
Schlosser, Jarvis Operations	411				
Patients followed	357	279	24	21	54
(per cent)		78	7	5.1	15

DISCUSSION

In analyzing our resection failures, we have not considered the morbidity of the operation. Small empyemas, which disappeared spontaneously after aspiration or required small thoracoplasties, wound infections, stump ulceration and the other postoperative annoyances familiar to the thoracic surgeon were all troublesome when present. In some instances they delayed a patient's discharge from the hospital, although his disease remained under control. Certain patients with mild respiratory embarrassment prior to surgery achieved stability of disease following resection and now remain with relatively the same extent of pulmonary crippling.

No effort has been made to determine the number of patients whose entire lung was removed as planned in their therapy, compared to the number

*We are indebted to Mrs. Dorothy Grinols, R.R.L., and Mrs. Gladys McGuirt, of the Firland Record Department for assistance in obtaining our follow-up data, and to Dr. John Fountain, who permitted use of the Tuberculosis Division, Seattle-King County Health Department records for this purpose.

of pneumonectomies performed because of vascular difficulties encountered technically or from the finding of unsuspected necrotic disease in the second lobe. Increased use of laminographic x-ray, as experience was gained, resulted in fewer unsuspected lesions. In future studies we hope to correlate closely the disease as seen by standard films and laminograms with that recovered in the surgical specimen.

At the outset of this study we were interested particularly in the deaths and complications related to inadequate pulmonary function. It is apparent to us from examination of such failures that the postoperative management of borderline function cases is vitally important. Had we been able to prevent or minimize the paradoxical respirations, retained secretions, minor peripheral lung leaks, phrenic or recurrent laryngeal nerve paralyses that occurred, at least during the immediate postoperative period, certain of these patients might have survived. In others, early tracheotomy, as suggested by Carter and Giuseffi[8] has been invaluable in their postoperative management. Other patients were felt to have adequate function and yet have already died with cor pulmonale. A major question pertains to the future course of those patients with low function reserve following resectional therapy. Is cor pulmonale eventually their fate? From our experience it would seem that this will be verified in a significant percentage.

Stump ulceration was a common but not a formidable problem. The late Dr. Lewis R. Roll[9] of the Firland Staff made a detailed study of the first 389 of these 400 patients and reported an incidence of over 24 per cent tuberculous ulceration of the bronchial stump. He predicted that stump ulceration would be a "minor problem in the future" once long-term drug therapy was prescribed with full knowledge of the sensitivity of the organisms to the drugs. Stump ulceration is now an extremely uncommon occurrence in the large group of patients subsequent to this series who have undergone segmental resection.

Early opening of a bronchial stump, indicating its insecure closure, has been uncommon. Even following pneumonectomy, fistula through the closed bronchial stump has usually been late in developing. In reoperated cases, search for the source of the bronchial fistula following lobectomy or segmental resection has shown the leak to arise from smaller bronchi in the raw surface of the lung. To us, these are indications that most of the late bronchial complications stem from unrecognized accumulations of fluid within the pleura, as pointed out by Stemmermann, Daniels, and Auerbach.[10] Contamination and low-grade infection in such accumulations, although frequently small, may result in a pleural abscess in which tubercle bacilli or pyogens of low-grade virulence are present. Such empyemas, we feel, always tend to seek an exit to the outside. They insinuate themselves through planes of low resistance, such as a tenuous closure of a bronchus, or through a small bronchus on lung surface formerly closed only by fibrin. The result is late bronchial fistula. To reduce these hazards to a minimum, it is necessary to give meticulous care to the obliteration of all pleural space as early as possible in the postoperative period.

In studying the readmission patients, it is apparent that the term "spread" is an extremely inaccurate one to apply to the manner of exacerbation of disease. In most instances there has been prior to surgery a definite tuberculous lesion in the region of the so-called "spread." Even though no shadow is seen in the x-ray, it is logical to accept the existence of a small necrotic lesion which later reactivates. The limitations of the ordinary x-ray film in demonstrating minute but significant leisons are recognized. Moreover, since "spread" connotes a reinoculation of lung parenchyma through a bronchogenic source, if this source is eliminated by a resection, as indicated by sputum conversion, then reactivation would seem to be the mechanism of subsequent extension of disease.

SUMMARY AND CONCLUSIONS

1. An analysis of the failures in a series of 400 consecutive patients undergoing resection for pulmonary tuberculosis is presented. Detailed study includes the early and late deaths, the readmission and multiple resection groups, and other failures. We feel that this study is helpful in the evaluation of present trends in surgical therapy of pulmonary tuberculosis.

2. Inadequate functional reserve has been a major cause of both early and late death.

3. Whereas major blowout of a bronchial stump indicating insecure closure was responsible for early death in two cases, a third of our late deaths were accountable to empyema with late bronchopleural fistula. The etiology of these late hazards in most cases is felt to stem from seemingly innocuous but persistent pleural fluid.

4. As demonstrated by our readmission and multiple resection group, residual caseous disease is a definite threat to a patient's future. In certain of these patients somewhat greater extension of the initial resection might well have prevented later surgery.

5. Reactivation rather than "spread" is usually the manner of exacerbation of disease following resectional therapy.

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LATE RECONSTRUCTION OF CONGENITAL ESOPHAGEAL ATRESIA BY INTRATHORACIC COLON TRANSPLANTATION

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THE optimal repair of congenital tracheo-esophageal fistula of the infant at present consists of ligation of the fistula and establishment of alimentary canal continuity by primary end-to-end esophageal anastomosis.[1] In some instances the primary suture of proximal esophageal pouch to distal esophagus is difficult or impossible because of the great distance between the esophageal ends. This situation has generally been managed by one of three methods: (1) mobilization of the entire distal esophagus and upper stomach to allow end-to-end esophageal anastomosis; (2) gastric mobilization and intrathoracic gastric transplantation to permit esophagogastrostomy; and (3) delay of reconstruction by performance of cervical esophagostomy and abdominal gastrostomy. The first two alternatives permit primary reconstruction but entail either an anastomosis of proximal esophageal pouch to a widely devascularized distal esophagus, or to the stomach which, by virtue of its presence within the thorax, imposes the disadvantages of gastric distention and regurgitation. The latter method of creation of skin stomas has necessitated prolonged and complicated later reconstructive procedures.

Two years ago we operated upon two infants for tracheoesophageal fistula, and primary anastomosis was not done. In the first instance, the anastomosis was done but ended with an obviously dangerous suture line. Rather than accept the almost certain leak and possible death, it was decided to perform cervical esophagostomy and abdominal gastrostomy until later reconstruction could be done. In the second case, there was complete atresia without a fistula. A two-inch fibrous cord connected the proximal and distal esophageal segments. Cervical esophagostomy and gastrostomy seemed preferable to mobilizing the stomach.

During the more than two years which intervened between the initial operations and final reconstruction, various possible reconstruction plans were considered, including the transplantation of stomach and jejunum into the chest. The experiences of others with the reconstruction problem were reviewed.

There appeared to be universal dissatisfaction with skin tubes used to bridge distances between the upper esophagus and stomach, chiefly because of the necessary multiple stages, the common occurrence of fistulas at either end,

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the development of strictures due to fibrosis and the extensive scarring of the anterior chest. Subcutaneous tunnels seem psychologically quite disadvantageous, particularly in a child.

Gastric transplantation and esophagogastrostomy have presented the problems of gastric dilatation and regurgitation, the development of peptic esophagitis of the proximal stump, and occasional difficulty in mobilizing the stomach to reach the neck.

The chief disadvantages of jejunal transplantation and anastomosis have been related to the length of the segment which could be mobilized and carried to the neck without necrosis, and the necessity for by-passing the stomach.

Recent experience here[4*] and elsewhere[2, 3, 5, 6] with intrathoracic colon transplantation following esophageal carcinoma resection led to its consideration for late reconstruction in congenital esophageal atresia. We were unable to find any report of experience with this procedure for bridging the defect of esophageal atresia.

RATIONALE OF ESOPHAGEAL RECONSTRUCTION USING INTRATHORACIC COLON

Theoretical and practical considerations indicate that intrathoracic transplantation of the right colon may avoid disadvantages of other types of esophageal reconstruction for congenital atresia of the esophagus in a child.

1. A one-stage reconstruction may be accomplished by laparotomy without formal thoracotomy. The right colon may be mobilized and pulled through the anterior mediastinum via a substernal tunnel dissected without actually opening the chest wall. Immediate anastomosis in the neck and to the stomach may then be performed through separate cervical and abdominal incisions. The chief disadvantages of a one-stage procedure appear to lie in the dangers associated with the five different suture lines necessary to this operation, as well as the possibility of contamination of the mediastinum. The development of antibiotic regimens and better methods of preparing the colon for anastomosis probably obviate most of this. That the entire procedure can be carried out within a reasonable time is evidenced by the four-hour operating time in these cases, which included time used to make photographic records.

2. The blood supply should be adequate and may be tested prior to division of any vessels by placing vascular clamps on the right colic vessels. In almost every instance the collateral circulation through the marginal arteries should be sufficient.

3. That the right colon will be long enough is attested by extensive clinical and experimental data and by experience in our autopsy room, where in each instance a sufficient length of right colon could be developed to bridge the distance between the neck and the stomach.

4. The incidence of peptic ulceration should be lower than when stomach, skin tubes, or jejunum is used.

*This article contains numerous references which are not repeated in the present paper.

5. The incidence of fistula formation at the site of anastomosis should be no higher than with other transplantations, particularly since this is probably related to the inadequate blood supply of the other types of anastomosis.

6. The procedure does not by-pass the stomach as does the jejunal transplantation.

7. Intrathoracic reconstruction is better than subcutaneous placement for psychological reasons, if for no others.

Possible disadvantages include stasis within the transplanted colon, compression of the stomach by the middle colic vessels passing over it, and stenosis at the anastomosis lines. In the two cases reported here Lipiodol x-ray examinations have indicated that the transplanted colon empties slowly. Regurgitation has occurred, however, only when oral feeding has been rapid. If compression of the duodenum or pylorus proves a real disadvantage, it should be possible to bring up the vessels and colon posterior to the stomach through the gastrohepatic ligament and thus avoid this compression. Should compression occur after anterior colon transplantation, gastrojejunostomy might be needed. The incidence of stenosis should be no greater than with other types of anastomosis. The use of fine interrupted nonabsorbable sutures is stressed.

CASE REPORTS

CASE 1.—R. C., SMH No. 332854, was born to a 23-year-old woman on Aug. 27, 1951. Birth weight was 2,150 grams (4 pounds, 11 ounces), and delivery was two weeks prior to the expected date. Crowing respirations and moderate cyanosis were observed. Twenty-nine hours later, because of an episode of excessive salivation and cyanosis, an unsuccessful attempt was made to pass a Levine tube into the stomach. After several hours and another unsuccessful attempt to pass the tube, Lipiodol injected via the tube confirmed the diagnosis of tracheo-esophageal fistula. The proximal esophageal stump lay at the level of the second thoracic vertebra (Fig. 1). Gas in the stomach and small bowel indicated the presence of a fistula. Preparations for thoracic exploration consisted of parenteral fluids, frequent nasopharyngeal aspiration, administration of penicillin, and placement of a cannula in the saphenous vein.

*Initial operation** was begun fifty-one hours after birth under cyclopropane and ether anesthesia. The right chest was entered through the bed of the fourth rib. After ligation of the azygos vein and incision of the mediastinal pleura, the fistula between distal esophagus and right main bronchus was found. This was cut and the bronchus sutured with interrupted 5-0 silk. The proximal esophageal stump was located high in the mediastinum and was dissected into the cervical region. The small distal esophagus was dissected free to the diaphragm. The segments were now 2.5 to 3 cm. apart. It was thought that primary anastomosis could be accomplished, and two posterior layers of interrupted 5-0 silk sutures were placed and successfully tied. The inner anterior layer of sutures then was placed. Upon attempting to tie these, the anterior sutures pulled out of the friable esophageal tissue and the posterior suture lines began to disrupt. Anastomosis without later disruption seemed impossible. Because of the poor condition of the premature baby and the torn condition of both esophageal ends the procedure was terminated by left cervical esophagostomy in anticipation of later esophageal reconstruction.

The following day a Stamm type gastrostomy was done under local anesthesia, leading the tube out of the left side of the abdomen from the anterior gastric surface. After an hour,

*Dr. G. O. Keller, and W. A. D.

normal saline gastrostomy injections were begun, and the infant was tolerating full formula via gastrostomy by the fourth postoperative day. Right upper pneumonia cleared gradually, and penicillin was stopped after seven days. The baby was discharged on the fifty-second hospital day weighing 3,280 grams (7 pounds 2 ounces).

The infant was seen at intervals for changes in formula and for cleaning the tube. Except for mild difficulties with the skin around the two stomas, development was excellent.

On Jan. 17, 1954, at the age of 2 years 5 months, he was readmitted for esophageal reconstruction, weighing 9.6 kg. (21 pounds). Aside from the esophagostomy and gastrostomy openings he was normal (Fig. 2). Preoperative preparation consisted of Neomycin, 0.25 Gm. and Sulfathalidine, 0.5 Gm. every four hours via the gastrostomy tube, daily tap water enemas and nightly milk of magnesia administration.

Fig. 1.—Lipiodol outlines proximal esophageal end preoperatively. Note gas in stomach. (All figures illustrate Case 1.)

The reconstructive operation was done on Jan. 22, 1954, under cyclopropane anesthesia. The right colon was transplanted into the anterior mediastinum and sutured proximally to the esophagus in the neck and distally to the stomach. The wounds were closed, but the gastrostomy tube was left in place. A partial left pneumothorax (secondary to mediastinal dissection) was treated by aspiration at the conclusion of the operation. The operative details are discussed later.

Postoperatively there were fever and tachycardia that responded to hydration within a few hours, after which there was no further fever. Penicillin and streptomycin were discon-

tinued after a week. Gastrostomy fluids were begun the third postoperative day after several stools were passed and were gradually advanced from 0.5 per cent saline to full formula. He took water by mouth the fourth postoperative day. By the twelfth postoperative day he was completely nourished by mouth in the form of liquid and soft baby food. The child swallowed poorly since he had no previous experience with the act. Occasionally, if feedings were taken rapidly, several spoonfuls were regurgitated. This was controlled by feeding more slowly. Barium swallow (Fig. 3) showed pooling of the material in the colon transplant but a follow-up film after twenty-four hours showed complete absence of barium except for a few flecks in the colon. The wounds healed well, and he was discharged on the sixteenth postoperative day in excellent condition (Fig. 4). A small fistula developed in the neck on the twentieth day, but was completely closed after four weeks.

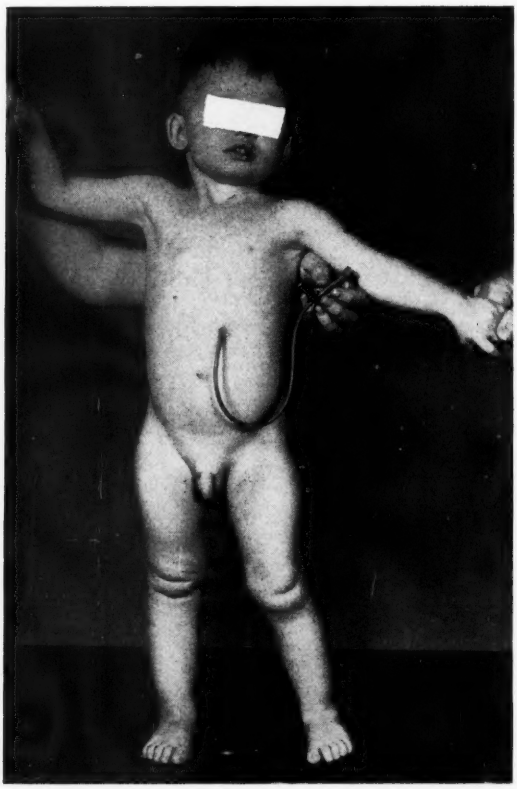

Fig. 2.—Case 1. Patient, aged 2 years 5 months, prior to esophageal reconstruction. Gastrostomy tube is in place.

Increasing difficulty in swallowing became apparent and Lipiodol swallow four months postoperatively showed complete stenosis of the cervical anastomosis between esophagus and cecum. Esophagoscopy confirmed this. The child was readmitted and on June 4, 1954, the cervical anastomosis was explored, finding a thin band of scar tissue completely closing the anastomotic stoma. The area was resected, and a new anastomosis was made between esophagus and cecum (three layers of interrupted 5-0 silk sutures).

The postoperative course was uneventful, and the baby was discharged on the eleventh postoperative day, eating well in small amounts. As of Oct. 4, four months postoperatively, the baby continued to do well.

CASE 2.—M. W., SMH No. 347881, the second child of a white 19-year-old woman, was born on July 16, 1952, weighing "over six pounds." At each feeding the patient vomited, choked, and became cyanotic. On the third day she was transferred to Strong Memorial Hospital, weighing 2,700 grams. The tentative diagnosis of tracheo-esophageal fistula was

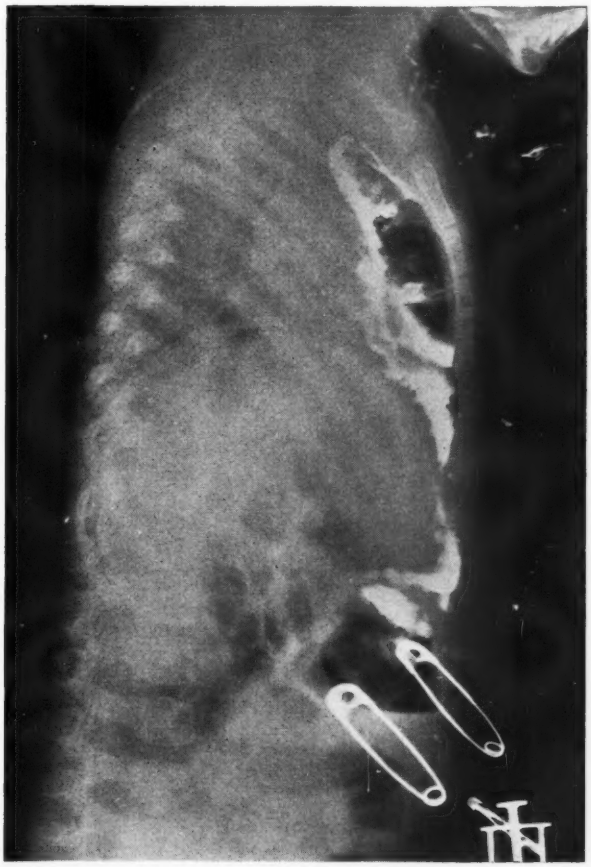

Fig. 3.—Case 1. Postoperative barium swallow showing anterior mediastinal position of transplanted colon (lateral chest view).

made, but Lipiodol swallow showed atresia without visualization of a fistula. No air was seen in the stomach or bowel. Preoperative preparation consisted of elevating the foot of her crib to help prevent aspiration, frequent nasopharyngeal suctioning, penicillin, oxygen, and hydration through a saphenous cannula.

At *initial operation* on July 20, 1952, under cyclopropane anesthesia there was esophageal atresia without a fistula. A two-inch long fibrous cord connected the proximal and distal

esophagus. Rather than transplant the stomach into the chest a cervical esophagostomy was done. On the following day a Stamm gastrostomy was performed, and feedings were begun through this on the suceeding day. The postoperative course was benign, and the patient was discharged on the eleventh postthoracotomy day, weighing 3,000 grams. She failed to gain weight and did poorly. The patient was followed in the clinic and finally was admitted to the hospital on June 21, 1953, weighing only 4,830 grams. A complete study failed to show any definite cause for her malnutrition. This included stool fat and trypsin content, vitamin A study, intravenous pyelogram, glucose tolerance, duodenal aspiration for enzymes, gastrointestinal series for enteric fistula, gastric acidity, and pepsin studies. We were unable to build the patient up in the hospital, and, since she represented a poor risk for surgery, she was discharged on July 31, 1953, hoping she could be built up on a celiac diet. Discharge weight was 5,180 grams, only 350 grams over her admission weight of 4,830.

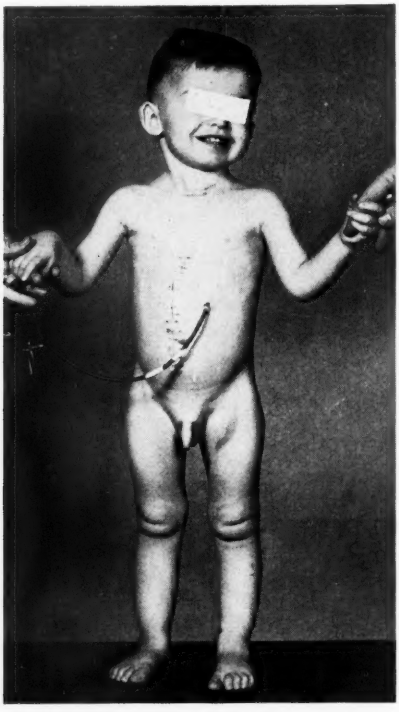

Fig. 4.—Case 1. Patient, fourteen days after operation; abdominal and cervical incisions well healed, gastrostomy tube still in place.

The third admission on Oct. 12, 1953, showed her to be more malnourished, having lost 620 grams, and weighing only 4,560 grams on admission. All of the studies of the second admission were repeated. Further studies included saliva analysis, oral and intravenous glucose tolerance tests, gastroscopy, Thorn tests, insulin tolerance tests, and nitrogen balance studies. No marked abnormalities were noted although there were one or two borderline results. With a high calorie celiac diet and careful nursing, the patient slowly gained weight. An extensive series of tests relating gastric response to a wide variety of

stimuli was done over a five-month period. She finally reached a weight of 7,530 grams, and seemed quite robust and ready for surgery. She was prepared for surgery in the same manner as the patient in Case 1.

On March 23, 1954, *esophageal reconstruction* was accomplished exactly as in the first case. Operation time was four and one-half hours, including frequent interruptions for movies. The postoperative course was very benign except for a slight fever of from 100° to 101° F., which subsided after the venous cut-down was removed on the third day. She was given a sucker on the eighth day, and an oral diet was given on the eighteenth postoperative day. She had some regurgitation intermittently which she did not seem to know how to handle. After she was placed on six small feedings daily, this was no longer a problem, and she slowly gained weight prior to discharge. On Aug. 27, five months postoperatively, she weighed 8,750 grams and was steadily improving.

TECHNIQUE OF INTRATHORACIC COLON TRANSPLANTATION

The preoperative plan of operation was followed. The steps of the procedure are discussed and illustrated.

1. *Preparation* for operation consisted chiefly in administration of Neomycin and Sulfathalidine to prepare the lower ileum and colon for section. Penicillin was used as prophylaxis of mediastinal infection.

2. *Incision* into the abdomen with wide exposure was obtained by right paramedian rectus retracting incision from the xiphoid to well below the umbilicus (see scar in Fig. 4).

3. *Right colon mobilization* was performed by cutting the lateral ascending colon and cecal attachments and dissecting in the avascular retroperitoneal area. The hepatic flexure was similarly dissected with due care for the duodenum. This permitted the right half of the colon and the terminal ileum to be lifted out of the abdomen (Fig. 5).

4. *Collateral vascular testing* was done by placing arterial clamps on the right colic artery near its origin (Fig. 6). The blood supply of the right colon was now obtained from the intact middle colic artery (forceps point to this) and the arcades of the marginal artery. After ten minutes there were excellent pulsations in the marginal artery and vessels supplying the cecum and ascending colon.

5. *Appendectomy* was performed while the vascular clamp was in place. The mesoappendix was serially ligated, the appendix cut between a proximal singly tied 4-0 silk ligature and distal clamp and the appendiceal stump buried between a purse-string cecal suture of 4-0 silk re-enforced by interrupted 4-0 silk serosal sutures.

6. *Section of the ileum* was performed between two obliquely placed clamps and the small vessels of the distal ileal mesentery and of the peritoneum medial to the ascending colon were ligated as well as the right colic artery and the ileocolic artery. The terminal ileal stump was turned in by a double layer of sutures. The colon could now be swung up onto the chest wall to ascertain at what point the transverse colon should be cut.

7. *Section of the transverse colon* was carried out to the left of the middle colic artery with care to avoid injury to the marginal artery. The transverse

Fig. 5.—Right colon fully mobilized and lifted out of abdomen. Forceps point to right colic artery. Ileocecal valve and appendix lie at lower left and transverse colon at top.

Fig. 6.—Right colic artery and terminal ileal arteries temporarily clamped to test vascular supply to right colon through middle colic artery (forceps at right) and marginal artery.

mesocolon was actually not cut down at all. The gastrocolic ligament to the right of the level of section of transverse colon was cut down and its vessels tied.

8. End-to-end ileum-transverse colon anastomosis was now performed in two layers, the outer of carefully placed interrupted 4-0 silks, and the inner as a continuous 4-0 chromic gut layer. The ileal and transverse colon mesenteries were approximated by interrupted 4-0 silk sutures to prevent small bowel herniation. The right colon could now easily be placed on the chest wall to illustrate its length (Fig. 7).

Fig. 7.

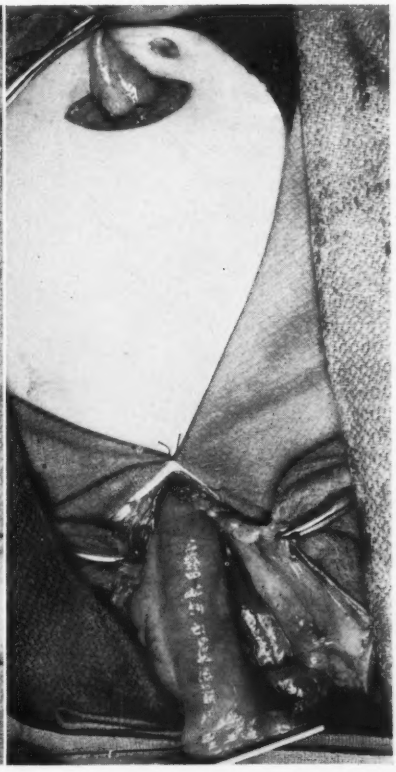

Fig. 8.

Fig. 7.—Right colon transected, free and lying on chest wall. Clamp is across transverse colon line of transection. Cecum (ileum and appendix inverted) lies at top near cervical wound. End-to-end ileotransverse colostomy lies below sponge at bottom.

Fig. 8.—Ascending colon pulled through substernal (anterior mediastinal tunnel) into neck. Top clamp holds stay suture in cecum. Lower clamp closes cut end of transverse colon.

9. Anterior mediastinal dissection to form a substernal tunnel was performed. Through a low-collar cervical incision the cervical investing fascia was opened transversely and the anterior mediastinal plane posterior to the

Fig. 9.

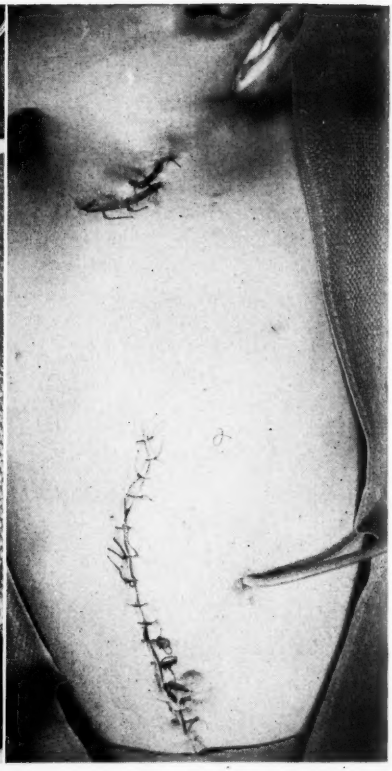

Fig. 10.

Fig. 9.—Anastomosis of proximal esophagus to cecum in neck, and of transverse colon to anterior surface of stomach in progress. Open two-layer anastomoses were simultaneously performed by two teams.

Fig. 10.—Wounds closed. Gastrostomy tube remains in place. Upper neck wound was esophagostomy site, and lower wound was anastomosis site. In the second case only one wound was made in the neck.

sternum entered with the finger. At the cephaled end of the abdominal wound the tip of the xiphoid was exposed and by combination sharp and blunt dissection a plane developed just posterior to the periosteum of the xiphoid process. Blunt finger dissection was now carried out both from below and above keeping close to the posterior sternal periosteum. A stay suture was placed in the tip of the cecum, and the cecum was pulled up through the substernal anterior mediastinal tunnel by means of this stay suture (Fig. 8). In the second case this stay suture was omitted, and the cecum was pushed through the tunnel by hand. The team was divided in half and the following two steps of esophageal-colon and colon-stomach anastomosis carried out simultaneously.

10. *Anastomosis of proximal esophageal pouch and cecum* was performed after mobilization of the esophagostomy and excision of the distal end. This

anastomosis was done entirely with interrupted 5-0 silk and consisted of three layers. There was no tension on the suture line at the end of the procedure. Fig. 9 illustrates both this and the following step in progress.

11. *Anastomosis of transverse colon and stomach* was performed near the lesser curvature, low on the anterior surface of the stomach with an outer layer of interrupted 4-0 silk and internal continuous 4-0 chromic gut. The transverse colon now arched upward from the anterior surface of the stomach and passed between the lobes of the liver up into the anterior mediastinum. Palpation of the colon and its vascular supply through the middle colic artery showed no tension existed.

12. *Wound closure.* Wounds were inspected for accurate hemostasis and closed with interrupted 4-0 and 5-0 silk sutures (Fig. 10). The gastrostomy tube remained in place since this had been walled completely out of the field, and it had not been necessary to dissect the stomach away from the anterior abdominal wall.

13. *X-ray examination* of the chest revealed 75 per cent left pneumothorax in the first case and 15 per cent left pneumothorax in the second. This was removed by simple needle aspiration and the lung re-expanded completely at once. This pneumothorax was the result of mediastinal dissection, which, although done as delicately as possible, was "blind" and ruptured the weblike pleura. Despite the absence of physical signs, it must be suspected after this dissection.

At the conclusion of the steps outlined above, the proximal alimentary canal of the child was reconstructed, while a gastrostomy tube remained in place for feeding purposes and as a precaution against anastomotic complications. There were five suture lines, namely: (1) upper esophagus to cecum, (2) distal stump of ileum, (3) appendiceal stump, (4) transverse colon to stomach, and (5) ileum to transverse colon. The condition of each child was good. The chief blood loss occurred during abdominal incision and was replaced through the saphenous cannula. Operative time was approximately four hours in each case.

DISCUSSION

Primary end-to-end esophageal anastomosis continues to be the best reconstructive procedure for esophageal atresia. This report in no way indicates that we feel otherwise, if the primary anastomosis can be accomplished with reasonable expectation of final success. However, if there is serious doubt regarding the viability of the anastomosis, or if such is impossible, many babies can be salvaged by delay in the reconstruction procedure, draining saliva via cervical esophagostomy, and feeding via gastrostomy tube. Delay in final reconstruction is preferable to the risk imposed by a determination to suture the two esophageal ends together, when the suture line is questionable.

The complications encountered are such that one should overcome them without too much difficulty. The anastomotic leak in the neck was handled with relative ease. In this procedure there is no intrathoracic anastomosis

which might lead to mediastinal abscess. The problem of stasis encountered in the second case was overcome clinically by reverting to frequent small feedings and gradually building up to a full three meals a day. However, cinefluorographic studies of a Lipiodol swallow showed continued slight delay of the passage of Lipiodol into the stomach and duodenum.

CONCLUSION

Two successful cases of intrathoracic transplantation of the right colon to reconstruct esophageal atresia are reported. The rationale of the procedure is discussed. The operative steps are detailed. Our initial success encourages further use of the operation in similar situations.

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HERNIATION OF THE LIVER

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HERNIATION of the liver through the right leaf of the diaphragm, though still rare, is being reported with increasing frequency. Although Hedblom[1] found only 14 instances of liver herniation in 857 cases of diaphragmatic hernia, and only 6 additional cases had been reported up to 1951,[2] several case reports have appeared since then.[2-6] The combination of increasingly severe trauma associated with automobile accidents, and the more expeditious and adequate treatment of the attendant shock, with survival of the patient, makes it likely that this condition will be increasingly encountered. Likewise, chest surveys of the population and routine hospital admission films will undoubtedly bring to light many previously undiagnosed and as yet asymptomatic cases. The position and appearance of the herniated liver are such as to suggest an intrathoracic tumor, either of the lung or diaphragm, and the diagnosis itself, though suspected, may be difficult to confirm without thoracotomy. In the past six years we have had the opportunity of treating four proved cases of hepatic herniation. Each of these posed a different problem, and from this experience we feel certain conclusions can be drawn.

CASE REPORTS

Case 1.—H. L. W., a 55-year-old white man, was admitted to the Oakland Veterans Administration Hospital on June 30, 1947. While crossing a highway on June 14, 1947, he was struck by an automobile and was hospitalized at a county hospital where a compound fracture of the right tibia and fibula was treated. He was unconscious, and when his condition permitted he was transferred to this hospital. On the Orthopedic Service x-rays revealed fractures of the right tibia and fibula in poor position, and these were corrected. A routine chest film on admission revealed elevation of the right leaf of the diaphragm and an oval density, apparently of the soft tissue, partially separable from the diaphragmatic shadow and extending to the level of the ninth rib in the cardiophrenic angle. Because of the patient's orthopedic condition no further attention was paid to this finding until November, 1947, when he began to complain of sharp pain in the right upper quadrant which was severe and colicky and radiated toward the left thorax. This suggested the possibility of a cholecystitis, and various gall-bladder tests were performed and an x-ray diagnosis of a nonfunctioning gall bladder was made. However, because of the presence of the mass as seen by x-ray in the right chest (Figs. 1 and 2), a diagnostic pneumoperitoneum was performed on Nov. 21, 1947, which resulted in a right pneumothorax and excellent delineation of the mass (Figs. 3 and 4). Thoracotomy was performed on Nov. 25, 1947. An incision was made over the eighth rib in the posterolateral chest on the right, and a segment of this rib was removed. On entering the pleural cavity, the lung was found adherent to the floor directly beneath the incision, and the adhesions were separated by sharp dissection. A large tumor mass was palpated over the anterior surface of the diaphragm which was identified as a lobe of the liver. An opening in the diaphragm was found which was constricted in a collarlike fashion around the lobe

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Fig. 1. Fig. 2.

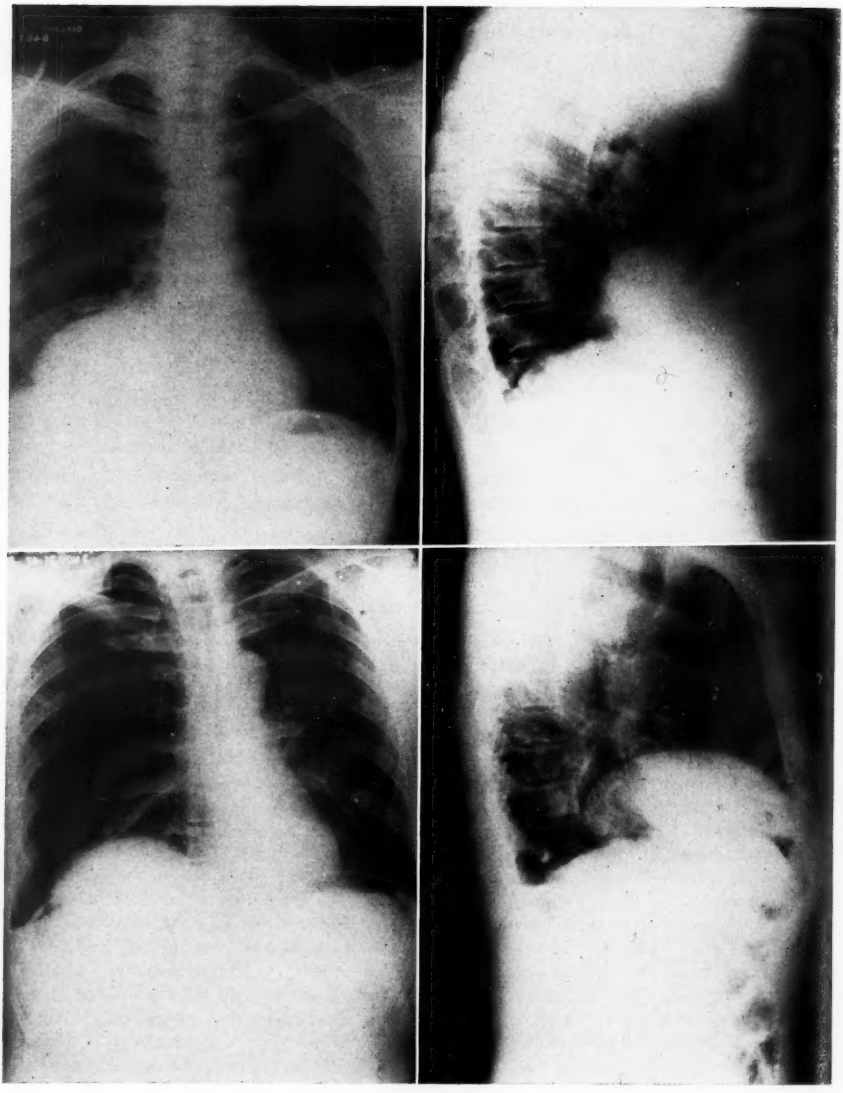

Fig. 3. Fig. 4.

Figs. 1 and 2.—Case 1. Admission x-rays. Note presence of mass in right chest.
Figs. 3 and 4.—Case 1. Following diagnostic pneumoperitoneum. Note right pneumothorax in Fig. 3 and characteristic mushroomlike mass in Fig. 4.

of the liver. There was a little difficulty encountered in clearing up the neck of the diaphragmatic opening, which measured about 4 inches in length and ran in a diagonal direction from the cardiac angle laterally and anteriorly. Some difficulty was experienced in reducing the herniated portion of the liver. Superior to the constriction, the liver had a grayish appearance caused by interference with the circulation. The herniation was reduced and the opening of the diaphragm closed with mattress sutures. Prior to this procedure the phrenic nerve was crushed over the pericardium for purposes of obtaining better relaxation. An intercostal catheter was placed in this space for drainage purposes. The patient made an uneventful recovery and when last seen at this hospital, in 1948, had no complaints referable to his chest or abdomen.

CASE 2.—F. C., a 39-year-old white man, was admitted to the Oakland Veterans Administration Hospital on June 4, 1951, complaining of left costovertebral pain associated with fever. He had a history of renal calculi dating back to 1937, and had had several previous hospitalizations for the same complaint. His past history revealed that in 1944 he was thrown from an automobile and sustained a head injury and fractures of both clavicles, several ribs, and the right pubic ramus. In 1945 he was hospitalized elsewhere for bilateral nephrolithiasis, and a right nephrolithotomy was done. During this procedure the right pleura was accidentally nicked and immediately repaired, but a pneumothorax resulted, and a small mass adjacent to the right heart border which had been overlooked on the routine film became apparent. A barium enema was done which showed no connection between the chest lesion and the colon. No further studies were made at that time. He re-entered that hospital on Sept. 19, 1949, for further investigation of his chest lesion. A gastrointestinal series and chest fluoroscopy revealed a sharply circumscribed, rounded mass overlying the right diaphragm medially and anteriorly, apparently attached to the diaphragm, but not to the heart. It was of uniform density throughout and formed no part of the gastrointestinal tract. He was discharged as "tumor of the diaphragm, nature undertermined." At the time of admission to this hospital, the chest x-ray (Figs. 5 and 6) showed that the mass had increased in size though it still was asymptomatic. Bronchoscopy was entirely normal, and a diagnostic pneumoperitoneum showed air under the right diaphragm (Figs. 7 and 8), but not in the chest or above the mass. On July 10, 1951, a thoracotomy was performed. Under endotracheal anesthesia, with the patient supine and the right side slightly elevated, an incision was made through the fifth intercostal space. Rib spreaders were inserted. The mass seen by x-ray proved to be a central diaphragmatic hernia 5 cm. in diameter through which incarcerated liver projected. The neck of the hernia was very tight and adherent. There was no defect through which air could pass, thus accounting for the inability to demonstrate the hernia on pneumoperitoneum. The liver was freed from adherent diaphragm and during this procedure a small rent was made in the liver capsule. This was filled with Gelfoam and sutured in place by Atraumatic catgut. The liver was returned to the abdomen and the diaphragm repaired by overlapping the edges with mattress sutures of No. 20 cotton. The phrenic nerve was crushed, one intercostal drainage tube placed dependently and connected to an underwater seal, and the incision closed in layers with cotton. The patient made an uneventful recovery.

CASE 3.—G. A. S., a 35-year-old white man, was admitted to the Oakland Veterans Administration Hospital on Oct. 14, 1953, complaining of a continuous, pressurelike dull pain across the lower anterior chest of eight weeks' duration. The pain was more intense on the right than the left side. There was no accentuation of pain on deep breathing or exercise. The pain was described as dull, pressurelike, and as though "something was pushing up on the right side of the chest" in the midanterior region. His history revealed that he was stationed in China in 1937. There he developed an acute diarrhea which lasted for four days and was diagnosed as bacillary dysentery. The stools were examined for amoebae, but none were seen. In 1938 he was hospitalized at a Naval Hospital in Shanghai, China, for pleurisy, at which time the stools were again checked for amoebae and none found. After the pleurisy had subsided, he was told that x-rays revealed a lump on his liver beneath the right diaphragm, and he was given two ten-day courses of emetine. Following discharge from the hospital the patient had three to four soft stools daily, occasionally with visible mucus, but there had been

Fig. 5. Fig. 6.

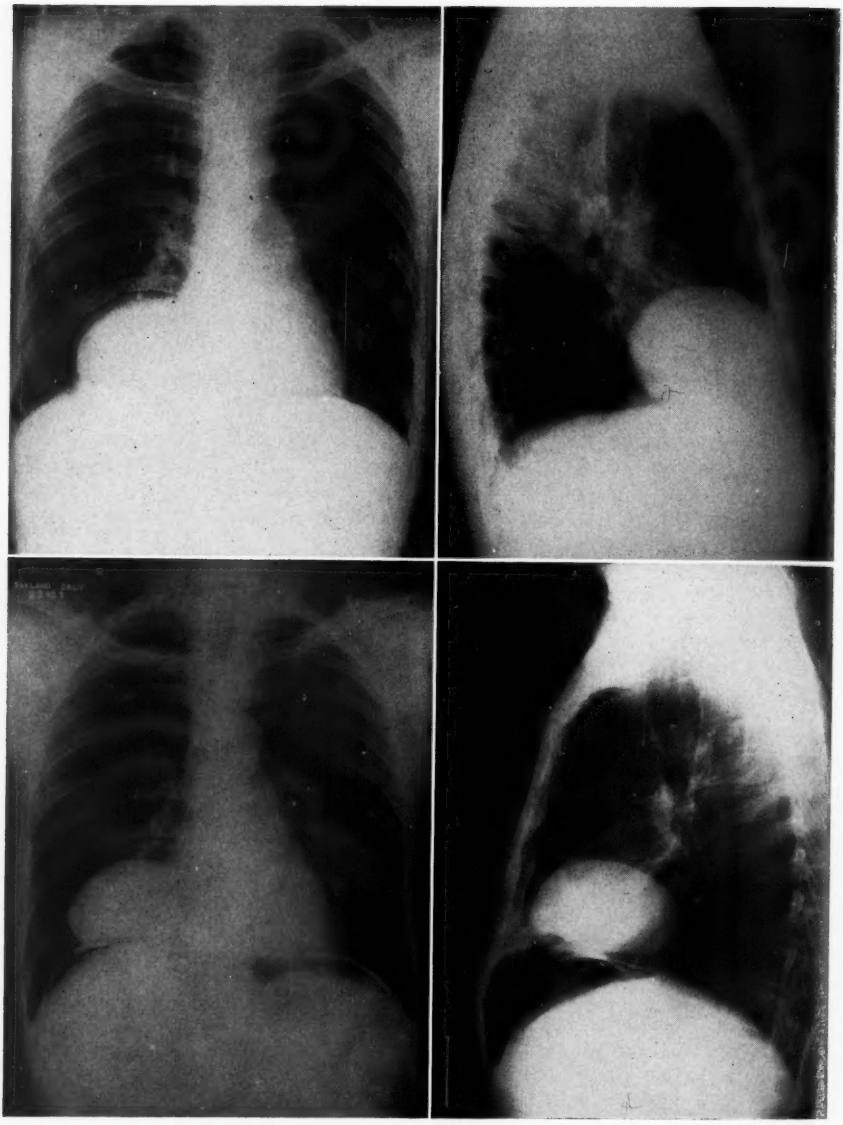

Fig. 7. Fig. 8.

Figs. 5 and 6.—Case 2. Note large mass in right chest adjacent to the heart.
Figs. 7 and 8.—Case 2. After pneumoperitoneum has been induced. Note mushroomlik mass on lateral view, Fig. 8.

no bright blood nor pus in the stools. In 1943 an episode of dysentery occurred for which he was hospitalized at the San Diego Naval Hospital for a period of one month. From 1943 on, the patient continued to have three to four soft, nonbloody stools daily, but every two months or so there would be a recurrence of diarrhea with passage of from six to eight watery, loose stools daily. Each bout would last anywhere from one to three days, subsiding spontaneously. These episodes seemed to be exacerbated by overindulgence in whiskey or the ingestion of improper food. At the age of 2 years, the patient had been run over by an automobile while lying face down on the ground. The wheel was stated to have passed over the lower portion of his chest. Although he recalled no definite details of this event, he was told by his mother that he was very sick at the time and had been hospitalized for ten days.

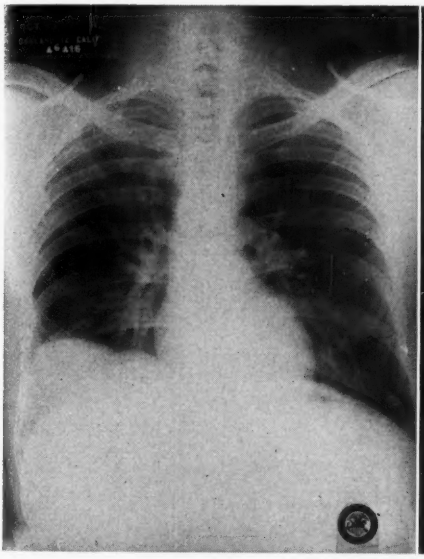

Fig. 9.

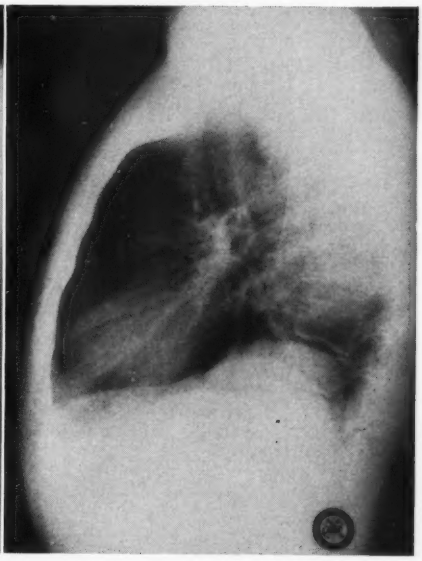

Fig. 10.

Figs. 9 and 10.—Case 3. Note mass in posterolateral aspect of right chest.

Physical examination was entirely normal except for slight tenderness over the right shoulder-strap area. The liver was not palpable, nor was any tenderness or mass felt in the abdomen. Examination of six different stool specimens was negative for amoebae, and no ova or parasites were seen. X-ray of the chest (Figs. 9 and 10) disclosed a rather sharply outlined oval shadow at the right base apparently distinct from the diaphragm. Barium enema revealed the entire colon filled readily and was normal in appearance. It did not extend up under the irregularly elevated diaphragm, but lay below the liver in the normal position. Fluoroscopy revealed irregularity of the right leaf of the diaphragm, but diaphragmatic motion was intact. On Oct. 26, 1953 a diagnostic pneumoperitoneum (Figs. 11, 12, and 13) was performed, and no air entered the thorax. The mass appeared to be located posteriorly, and it was difficult to determine whether it was adherent to or above the diaphragm. On Nov. 20, 1953, an exploratory thoractomy was performed with resection of a portion of the right ninth rib. At operation a portion of the right lobe of the liver, measuring approximately 2½ inches in diameter and approximately 3 inches in length, was found to have herniated through the right leaf of the diaphragm. A tight neck was present around the herniated portion consisting of thinned-out fibrous diaphragm and diaphragmatic pleura. There were filamentous adhesions to the right lower lobe of the lung. There were no muscle fibers over the dome of the herniated liver. The liver was covered by a thinned-out diaphragmatic pleura

Fig. 13.

Fig. 12.

Fig. 11.

Figs. 11, 12, and 13.—Case 3. The pneumoperitoneum emphasizes the mushroomlike mass representing the herniated liver.

and the right coronary ligament, which was adherent to it. The sac of the hernia was trimmed at its adherent portion about the neck and the dome of the liver. The liver was returned to the abdominal cavity, and the diaphragm closed over by mattress sutures. Palpation of the liver revealed no abnormalities. His postoperative course was uneventful and he was discharged from the hospital on Nov. 30, 1953.

CASE 4.—G. A. C., a 59-year-old white man, was admitted to the Oakland Veterans Administration Hospital on Feb. 23, 1954. He complained of weakness, anorexia, weight loss, and, for the past six months, an irritating, hacking, nonproductive cough with exertional dyspnea. In 1945 he was in an automobile accident sustaining fractures of the eighth and ninth ribs on the right, and requiring a thoracentesis. He had previously been hospitalized elsewhere from Feb. 23, 1949, to April 18, 1949, at which time an x-ray of the chest revealed old fractures of the right eighth and ninth ribs posteriorly, and a mass at the base of the right lung. No diagnosis of the mass was made. At the time of admission to the Oakland VA Hospital an x-ray of the chest (Figs. 14 and 15) disclosed the presence of a mass on the

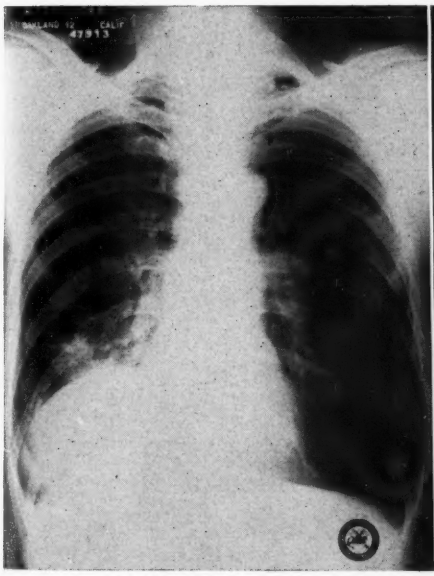

Fig. 14.

Fig. 15.

Figs. 14 and 15.—Case 4. Note mass in right chest.

right just above the diaphragm. Pneumoperitoneum induced on March 9, 1954, revealed (Figs. 16, 17, and 18) a rounded, regular mass with a characteristic mushroomlike appearance best seen on the oblique view with air in the hernial sac. The diagnosis of herniation of the liver was made, and on March 15, 1954, a right thoractomy was performed with resection of a portion of the seventh rib. A mass 3 inches in diameter was present. It was a portion of the right lobe of the liver which had herniated through the right leaf of the diaphragm anterior to the right coronary ligament. There was a definite hernial ring, and the covering of the hernial sac consisted of diaphragmatic and visceral pleura. Biopsy specimens taken from the neck of the hernial ring as well as from the covering of the hernial sac showed that they consisted of pleura. The hernial ring was freed, the right lobe of the liver reduced into the abdominal cavity, and the defect in the right leaf of the diaphragm repaired by suturing. His postoperative course was uneventful, and he was discharged from the hospital on March 29, 1954.

Fig. 16. Fig. 17. Fig. 18.

Figs. 16, 17, and 18.—Case 4. Pneumoperitoneum reveals the mushroomlike mass enclosed in a hernial sac. This is best demonstrated in the lateral view, Fig. 17, and the oblique view, Fig. 18.

DISCUSSION

Etiology.—The etiological factor in all our cases was severe trauma to the thorax usually associated with multiple rib fractures. Although the history of trauma may be readily obtained even after many years, in one instance (Case 3) only after close questioning was this information elicited. Congenital defects in the right leaf of the diaphragm may allow the liver to herniate through it, and such cases have been reported.[6] The probabilities are that such herniations would produce symptoms and be discovered long before the individual reached adult life.

Symptoms.—It is interesting to note how long the patient can remain symptom-free after the trauma occurs. The time interval between the traumatic episode and surgery varied in our cases from five months to thirty-three years. In the case reported by Child and his associates,[2] the traumatic hernia had occurred forty-four years prior to operation, although gastrointestinal symptoms had been present for only twelve years. Similarly, in the case described by Knoepp[3] trauma had occurred eighteen years before surgery. Symptoms occur only when the mass increases sufficiently in size to produce cardiopulmonary embarrassment,[3] or, if sufficient constriction occurs, then right upper quadrant pain or substernal distress may result due to interference with the blood supply and the production of early strangulation of the liver substance. This has been reported by Wolfson and Goldman.[5] Similarly in our first case, definite impairment of circulation was noted at the time of operation. The liver had a grayish color which rapidly disappeared when the constriction was freed. A biopsy of the liver at the time of surgery revealed normal liver parenchyma. It may be that the onset of symptoms long after herniation has occurred is caused in part by the descent and flattening of the diaphragm which occurs with aging and accompanying emphysema.

Diagnosis.—A careful history inquiring as to the possibility of severe trauma is most important. Frequently the injury has taken place so many years ago that the patient fails to recall it, or feels it has no connection with his present complaints. Such was the situation in Case 3, where, after the diagnosis was entertained, careful questioning of the patient revealed a history of severe trauma at the age of 2 years. The presence of a mass as seen by x-ray for a period of years, which has been relatively asymptomatic, if not entirely so, should also make one suspicious of this possibility. In every instance a characteristic picture of a circumscribed, rounded, mushroomlike mass lying above the diaphragm and intimately associated with the right heart border is seen on x-ray. It has been suggested by numerous authors[2, 4, 5] that pneumoperitoneum is an excellent tool in the diagnosis of this condition. Certainly if pneumoperitoneum is induced and air enters the thorax, a rent must be present in the diaphragm. This is well demonstrated in Case 1. It must be emphasized, however, that if the condition is of longstanding and a tight constriction is present around the herniated liver, no air can pass through into the chest. Likewise, dense adhesions between the diaphragmatic and visceral pleura may also seal off the communication by forming a sac (Case 4). It is therefore

stressed that while this test may be of positive value in demonstrating a communication between the abdomen and thorax, the absence of such communication does not in any way exclude the diagnosis. Our second, third, and fourth cases demonstrate this point very well. Pneumoperitoneum, however, does emphasize the characteristic mushroomlike mass which is seen on the x-ray.

Treatment.—The treatment of this condition is the same as that for any other hernia. A thoractomy should be performed, the liver returned to the abdominal cavity, and the defect repaired. This is a simple procedure, does not require prolonged hospitalization, and definitely establishes the diagnosis. The symptomatic case requires immediate surgery because of the possibility of strangulation. This is well-demonstrated by Case 1 where definite impairment of blood supply to the herniated liver was noted at the time of operation with immediate return of normal color when the herniation was reduced. In our second case, the lesion had been diagnosed elsewhere as "tumor of the diaphragm" and caused the patient considerable anxiety. The impossibility of making an absolute diagnosis without thoracotomy led to the repair of the hernia and the relief of the patient. In our third case the patient had been treated on numerous occasions for amoebic abscess because of a history of dysentery while serving in China in 1937 and the presence of a "bump" on his liver as seen by x-ray. In fact, his complaint of "something pushing up on the right side of the chest" was interpreted as increasing tension of an hepatic abscess. The failure by numerous physicians to properly establish the correct diagnosis led to frequent periods of hospitalization, loss of work, and recurrent courses of emetine. The fourth case had frequent admissions to hospitals with vague symptoms referred to the right upper quadrant of the abdomen, and without a proper diagnosis.

We do not feel that this lesion should be allowed to remain because it is asymptomatic at the time of discovery. Certainly our experience as well as that of others has shown that symptoms do become apparent and troublesome years after the lesion is first found.

SUMMARY AND CONCLUSIONS

The presence of an asymptomatic intrathoracic mass in the right lower chest poses a problem in differential diagnosis. One of the conditions to be considered is hepatic herniation. This is rare and, in adults, usually follows severe trauma. It may be asymptomatic for years, first being discovered during the course of a routine chest x-ray. Occasionally symptoms occur consisting essentially of pain in the right upper quadrant of the abdomen or across the right lower chest. This may grow in intensity and is usually secondary to the increasing size of the mass with encroachment on neighboring structures or strangulation of the liver. In practically every instance the x-ray presents a typical appearance, that of a circumscribed, rounded, mushroomlike mass lying above the diaphragm and intimately associated with the right heart border. Though pneumoperitoneum may help in establishing the diagnosis in early cases, frequently the rent in the diaphragm is sealed off by the large mass of liver protruding through it. However, the use of pneumoperitoneum

does serve to emphasize the characteristic x-ray appearance of the lesion. Barium enema, gastrointestinal series, chest fluoroscopy, and bronchoscopy are useful in excluding other diagnoses. A careful history inquiring into past severe trauma is of the utmost importance. Since these lesions tend to increase in size over the years, eventually producing symptoms, and the possibility of missing a tumor is always present, it is urged that all suspected hepatic herniations be explored and corrected.

We are indebted to Miss Maude Greenwood, Chief, Medical Illustration Laboratory, and to Mr. Jack F. Shepley, medical photographer, for the x-ray reproductions.

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FIBROSARCOMA OF THE BRONCHUS

Report of a Case

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PRIMARY fibrosarcoma of the bronchus is a lesion of considerable rarity. Whereas in the older medical literature reports of pulmonary fibrosarcoma were quite frequent, it is now known that the great majority of these reports actually represented undifferentiated carcinomas, or lymphosarcomas of the mediastinum with extension to the lung.

Adler,[1] in his book published in 1912, listed ninety cases of pulmonary sarcoma. The lack of accurate pathologic description made it impossible to establish a single one of his cases as being a primary fibrosarcoma of the bronchus.

In a review of the literature in 1931, Ball[2] found fourteen cases of pulmonary sarcoma and added one case of his own. In a detailed analysis of these cases, however, only the cases of Ball[2] were found to be adequately authenticated. But even these two cases so extensively involved the lung that their exact sites of origin could not be defined accurately.

In 1950, Black[3] was able to find only five authenticated cases of primary fibrosarcoma of the bronchus in the entire medical literature. To these he added one case of his own. In the same journal in which Black's paper was published, Carswell and Kraeft[4] reported an additional case.

Stout[5] has greatly clarified the somewhat confused picture of fibrosarcoma. He has pointed out that the tumor is primarily characterized by the formation of collagen and reticulin fibers in varying amounts. The individual cells are usually spindle shaped, and mitotic figures are rare since the tumor is usually slow growing. The presence of giant cells is uncommon.

Stout[5] recognizes two forms of fibrosarcoma, the well-differentiated and the poorly-differentiated. In the well-differentiated tumors the collagen and reticulin fibers are wrapped around the cells, and these bundles or cords of spindle-shaped cells and fibers are usually arranged in gentle curves, but abrupt changes in direction of these cords may occur giving the appearance of whorls on cut section to which some authors have given the name "neurogenic fibrosarcoma." The cells of the well-differentiated tumors are uniform without much hyperchromatism, with well-developed collagen and/or reticulin fibers and few or no mitoses. In the poorly-differentiated tumors the cells are closely packed with little or no collagen and only delicate reticulin fibers. There is some hyperchromatism, and mitoses are frequent.

Of the five cases of fibrosarcoma of the bronchus reported by other authors and listed by Black,[3] in only one was pulmonary resection attempted. The pa-

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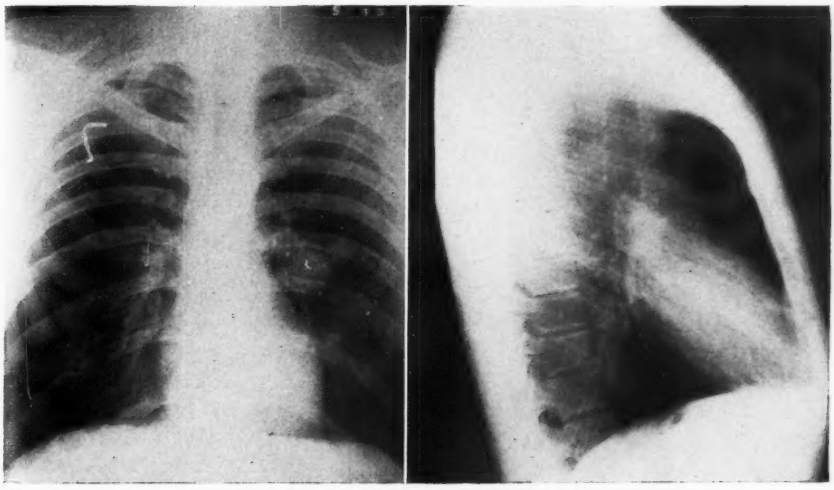
tient, however, died during surgery of pulmonary hemorrhage. In another case, no treatment was given. In the three remaining cases the lesion was removed endoscopically. In Black's case and in the case reported by Carswell and Kraeft,[4] pneumonectomies were performed.

Ochsner, DeBakey and associates[6] reported one case of a neurofibrosarcoma removed by pneumonectomy with a survival of twelve years, but the site of origin of the tumor was not given. Stout[5] would classify this as a fibrosarcoma. Mallory[7, 8] reported two cases of fibrosarcoma in which pneumonectomy was performed, but in each case it could not be definitely established whether the lesion was primary or metastatic.

The paucity of reports of proved pulmonary fibrosarcoma leads us to report a case which we believe to be a well-verified primary fibrosarcoma of the bronchus for which a pneumonectomy was performed, with survival of thirteen months to date.



A. *B.*

Fig. 1.—Posteroanterior (*A*) and lateral (*B*) chest plate showing a round shadow in the left hilar region.

CASE REPORT

H. S., a 40-year-old white man, was admitted to the hospital because of a suspicious lesion in the left lung which had been detected by a roentgenogram of the chest taken during a routine physical examination. He gave a history of upper respiratory infection which had been present for three months, associated with a dull ache in the left chest.

Physical examination was entirely negative except for the presence of some tenderness over the left chest in the precordial region.

Laboratory studies were within normal limits. A chest plate (Fig. 1) showed a round, well-circumscribed shadow in the left hilar region about the size of a silver dollar. Bronchoscopy done the day following admission was negative. Thoracotomy was performed on the fifth hospital day. At surgery a mass was found in the hilum of the left lung in the

interlobar fissure and lingula. A biopsy of the mass was taken which was reported on frozen section to be malignant. A pneumonectomy was therefore performed. The patient's postoperative course was entirely uneventful, and he was dismissed from the hospital on the tenth postoperative day.

At present, the patient is alive and completely asymptomatic, thirteen months following surgery.

Fig. 2.—Gross photograph of resected specimen. The lumen and the involved bronchus have been sectioned longitudinally and the halves spread apart. The tumor surrounds and causes stenosis of the segment of bronchus seen passing horizontally across the upper third of the figure.

Gross and Microscopic.—The gross specimen consisted of a lung weighing 260 grams. There was a tumor mass arising from the superior branch of the lingular bronchus. This mass was demarcated from the surrounding tissue but not encapsulated, was roughly spherical in shape. It measured 2.5 cm. in diameter and completely surrounded the bronchus, which was eccentrically placed in the tumor. There was a marked stenosis of the bronchus with ulceration and loss of bronchial mucosa (Fig. 2). Section of the mass showed it to be yellow-white in color, moderately firm, and noncystic, with masses of tumor tissue organized in whorllike formation.

Microscopically, the tumor showed numerous bundles of elongated fusiform cells which interlaced and anastomosed freely with each other. In the individual fascicles the cells showed a mild degree of pleomorphism, although the majority of cells were spindle shaped. Many nuclei were markedly enlarged, hyperchromatic, and showed bizarre configurations. Abnormal mitoses were scattered in small numbers throughout the tumor. The bronchial mucosa was absent, the bronchial surface being made up of tumor tissue. Beneath the surface a few bronchial glands could be seen surrounded by infiltrating tumor. (Figs. 3-5.)

A Masson stain demonstrated the production by the tumor cells of a small amount of fibrillar intercellular collagen, and a Wilder stain showed a large amount of reticulum throughout the entire tumor.

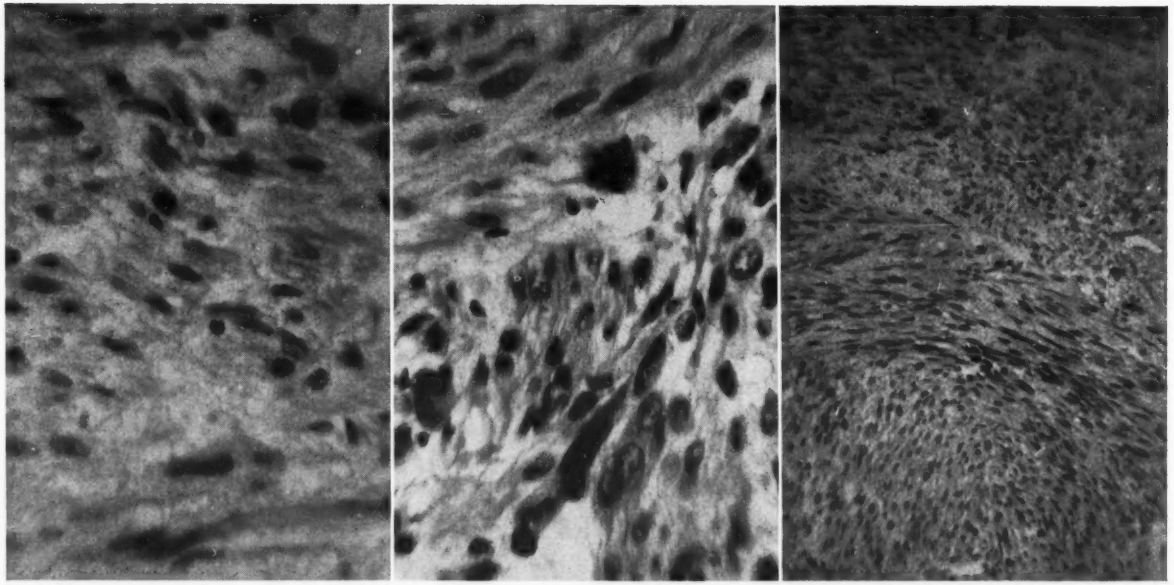


Fig. 3. Fig. 4. Fig. 5.

Fig. 3.—Fibrosarcoma of the lung. Note fasiculation. Palisading of nuclei is present in the longitudinally cut fibrous tissue bundle. (Magnification ×100; reduced ¼.)

Fig. 4.—Fibrosarcoma of lung showing nuclear pleomorphism and giant hyperchromatic nuceli. (Magnification ×430; reduced ¼.)

Fig. 5.—Fibrosarcoma of lung; abnormal mitoses. (Magnification ×430; reduced ¼.)

DISCUSSION

We are in accord with Black[3] in believing that these tumors, despite their often slow growth, should be removed by pulmonary resection. Endobronchial removal of these lesions, when feasible, in no way assures their complete removal. As in other neoplastic diseases of the lung, radical surgery provides the best hope for cure.

SUMMARY

1. A brief résumé of the medical literature on fibrosarcoma of the bronchus is presented.

2. A case of primary fibrosarcoma of the bronchus, treated by pneumonectomy, is reported. The patient is alive and well thirteen months postoperatively.

3. It is believed that pulmonary resection is the rational method of treatment of pulmonary fibrosarcoma.

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THE CAUSES OF DEATH FOLLOWING ESOPHAGEAL RESECTION FOR CARCINOMA

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THE surgical treatment of primary epidermoid carcinoma of the esophagus has been found to be extremely unsatisfactory in our experience. With few exceptions, all of our patients with carcinoma of the esophagus have presented themselves in a moderately severe to severe state of dehydration and malnutrition. A high proportion of the tumors are situated in close proximity to the region of the aortic arch and the bifurcation of the trachea. The technicalities involved in the extirpation of tumors in this region when combined with restoration of the alimentary tract in a single-stage operation are more complicated than in the less frequently involved terminal esophagus. Even so, the salvage rate might be more presentable were it not for the fact that the operative mortality rate has been very high. In those surviving, the long-term results have been very poor.[10] Others[4, 6, 12, 14] have reported a somewhat similar experience.

In an attempt to find some reason or reasons for the extremely poor results, we have analyzed our cases with particular regard to the causes of death following treatment by resection.

In the 13½-year period between Jan. 1, 1940, and June 30, 1953, 210 patients were observed with histologically proved epidermoid carcinoma of the esophagus. We have observed no cases of adenocarcinoma primary in the esophagus. No case of adenocarcinoma of the stomach invading the esophagus is included in this series.

The relative incidence of primary epidermoid carcinoma of the esophagus and primary malignancies in the stomach, colon, rectum, and other sites has been reported in an analysis of an earlier series.[10] In our experience, carcinoma of the esophagus is the most common malignant neoplasm in the alimentary tract. Also in the same report, observations were made on other features of carcinoma of the esophagus, notably its great preponderance in the Negro, the high incidence of involvement of the region of the arch of the aorta, and the methods of diagnosis, treatment, and results.

The uppermost levels of involvement of the esophagus in 199 cases in which it could be determined accurately are shown in Table I.

TABLE I. LEVEL OF LESIONS

		CASES	PERCENTAGE
Cervical		18	9
Upper fourth	Thoracic	14	7
Middle half	Thoracic	141	71
Lower fourth	Thoracic	26	13
Totals		199	100

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TABLE II. OPERABILITY AND RESECTABILITY RATES

Cases	210
Inoperable	138 (66%)
Operable	72 (34%)
Nonresectable	29 (40%)
Resectable	43 (60%)
Palliative	32 (74%)
Curative	11 (26%)

The operability and resectability rates for the 210 cases are shown in Table II. The reasons for inoperability were the wide extent of the local lesion (such as invasion of the trachea or of a bronchus), distant metastasis, or both, or severe malnutrition without improvement on therapy. Of the resectable cases, only one in four could be considered to have had a theoretically curative resection. The 11 cases having a theoretically curative resection represented only 5.2 per cent of the entire group of 210 cases.

All of the cervical lesions explored were found to be nonresectable.

There were 43 cases with involvement of the thoracic esophagus treated by resection. Early in the series there were 4 cases treated by the Torek procedure. The remaining 39 cases were treated as described here. In one case, a two-stage operation was performed. At the first stage, the stomach and esophagus were mobilized through a median sternotomy in continuity with a vertical upper abdominal incision. At the second stage, using a right thoracotomy approach, an esophagogastrostomy was performed above the level of the arch of the aorta. In one case, a right anterior thoracotomy approach was used, after mobilization of the stomach through a separate abdominal incision, with restoration of continuity by an intracervical esophago-esophageal anastomosis. The remaining 37 patients were treated by restoration of the continuity of the alimentary tract in a single-stage operation through a left thoracotomy approach, using the stomach to replace the resected portion of the esophagus, except in three cases, as follows: an esophagojejunostomy in the neck was performed in one, a plastic tube[1] was used to replace the resected portion of the esophagus in another, and an esophago-esophagostomy in the thorax without transplantation of the stomach[9] was performed in another. None of the patients treated by resection had had a preliminary gastrostomy.

The mortality rates in the cases treated by resection are shown in Table III.

Before proceeding with an analysis of the causes of death following resection, it must be said also that in the 29 cases which were operable but nonresected, there were 5 deaths as a direct result of the operation and 2 deaths after recovery from the operation but prior to discharge from the hospital. The mortality rate as a direct result of the operation was 17 per cent. The causes of death in the 5 cases were unrelieved tracheal obstruction in one, postoperative shock and empyema in one, uncontrolled hemorrhage due to laceration of the aorta in one, blood transfusion reaction in one, and hemorrhage from the trachea in the presence of a tracheotomy in one. The causes of death in the 2 cases in which death occurred following operation and before discharge from the hospital was inanition.

TABLE III. TYPES OF RESECTION AND ANASTOMOSIS FOR THORACIC LESIONS

	CASES	SURVIVED	DIED	MORTALITY RATE (%)
Torek	4	1	3	75
E-E* cervical	1	0	1	100
E-G† cervical	8	4	4	50
E-J‡ cervical	1	0	1	100
E-G above arch	11	5	6	55
E-G at arch	6	2	4	66
E-G below arch	10	6	4	40
Plastic tube	1	0	1	100
E-E thoracic	1	1	0	0
Totals	43	19	24	56 average

*E-E = Esophago-esophagostomy.
†E-G = Esophago-gastrostomy.
‡E-J = Esophago-jejunostomy.

The causes of death in the 24 cases of carcinoma of the thoracic esophagus treated by resection are shown in Table IV. It will be noted that in 11 cases empyema developed on the operative side. Most often this was due to failure of healing of the anastomosis with esophagopleural fistula. The resulting empyema did not improve following the institution of adequate drainage and discontinuance of oral feedings. Parenteral feedings or jejunal feedings were substituted. The jejunal feedings were given either by a tube passed transnasally into the jejunum, or by jejunostomy.

The high mortality rate following resection warrants a review of the status of the patients on admission, and of our methods of preoperative therapy, operative technique, and postoperative therapy.

TABLE IV. CAUSES OF DEATH FOLLOWING RESECTION OF THE THORACIC ESOPHAGUS FOR CARCINOMA

	CASES
Anastomotic leak and empyema	9
Leak around plastic tube and empyema	1
Empyema with anastomosis intact	1
Blood transfusion reaction	3
Excessive blood loss	2
Excessive fluid and electrolyte administration	2
Lobar pneumonia and chronic pyelonephritis	1
Cardiac failure	1
Mediastinitis and chylothorax	1
Adrenal cortical failure	1
Vago-vagal reflex and anoxia	1
Incompatible blood	1
Total	24

STATUS OF PATIENTS ON ADMISSION

One would think that the duration of symptoms in carcinoma of the esophagus would be of particular significance. Since dysphagia is the most frequent symptom, its duration should represent the length of time in which the patient is subjected to an increasingly restricted diet, and therefore reflect in some measure the extent of the lesion and the degree of loss of weight and strength. In the 24 patients who died following resection, the average duration of symptoms was four months, with extremes of four days and twelve months, and the average weight loss was 26 pounds, with extremes of zero and 55 pounds. The

weight loss expressed in terms of the percentage of total body weight averaged 17 per cent, with extremes of zero and 43 per cent. In contrast, in the 19 patients who survived resection, there was no significant difference in the same observations.

Many cases showed hemoconcentration before hydration, as one would expect. After hydration and before blood transfusions, anemia was present in 14 of 24 patients who died following operation. Anemia was present in the same degree in those who survived resection.

Abnormalities in the serum protein determinations were noted in 8 of the 22 patients in whom determinations were made, among the 24 patients who died following resection. There were noted a reduction in the total serum proteins in 4 cases and a reduction in the albumin component in 7 cases, varying from slight to marked, with reversal of the albumin-globulin ratio in some. In contrast, among the 19 patients who survived resection, serum protein determinations were available in 12. In none of the 12 cases was there a reduction in the total serum proteins, but in 7 of the 12 cases the albumin was reduced, with reversal of the albumin-globulin ratio in several.

Serum sodium, potassium, and chloride determinations were normal in all patients on whom such determinations were made, except in one in whom hyponatremia and hypokaliemia were present on admission. This condition was corrected easily and promptly.

In addition to carcinoma of the esophagus, a total of 17 diseases was found in 16 of the 24 patients who died following operation. Hypertension and significant arteriosclerosis were found in 4 cases, uncomplicated hypertension alone in 2 cases, diabetes in 1 case, unexplained hepatomegaly in 1 case, nephrosclerosis with a blood urea nitrogen of 30 mg. per cent in 1 case, transient pneumonia in 1 case, chronic osteomyelitis of the femur in one case and chronic alcoholism in 1 case. None of these was considered to be a contraindication to operation, and in none who died was there any concrete evidence that any of these abnormalities had contributed to death.

In contrast, in the 19 patients who survived esophageal resection, there were 6 patients with diseases other than carcinoma of the esophagus. Two had hypertensive cardiovascular disease, one had pulmonary emphysema not clinically significant, one had a positive Wassermann, one had granuloma inguinale, and one had a nodular goiter which was removed prior to esophageal resection.

In only 1 of the 24 patients who failed to survive resection was there any evidence prior to operation of extension of the tumor beyond the esophagus which could be ascertained by clinical or accessory examination. The one case had a firm palpable supraclavicular lymph node which was not biopsied.

PREOPERATIVE THERAPY

Restorative therapy consisted of the administration of intravenous fluids, or of forced feedings via a transnasal intragastric Levin tube supplying proteins, fats, carbohydrates, and vitamins with provision of as many calories as possible; of blood to correct anemia; and of treatment of associated diseases when indicated. Therapy was continued from 4 to 61 days preoperatively in

the 24 patients who died following resection. The average duration of therapy in those who died was 17 days. The average duration in those who survived was 16 days, with extremes varying from 2 to 30 days.

Despite this period of preoperative therapy, the mean weight gain was only 1 pound in the 24 patients who died following resection. The extremes were loss of 5 pounds and gain of 10 pounds. The 19 patients who survived following resection also showed no weight gain in the average case, with variations from 10 pounds lost to 8 pounds gained. However, both groups showed a significant preoperative gain in strength and general appearance by clinical appraisal which could not be related to the weight changes.

Hormonal therapy[2] preoperatively was used in only 1 of the 43 cases treated by resection. Testosterone was used in this one in an effort to produce a positive nitrogen balance, but this patient died. ACTH and cortisone were not used.

OPERATIVE TECHNIQUES

The operative technique for the Torek procedure need not be described. With the exception of the first case operated on after World War II (1946), the Torek procedures were performed during the war in the early periods of assessing the surgical treatment of carcinoma of the esophagus in this institution.

The operative technique used in the majority of cases has been described in a previous report,[10] and the precise operations performed in all cases in this series have been enumerated. The method of anastomosis used was based on earlier experimental work.[9, 11]

In most cases, blood was given intravenously throughout operation. In those patients who died following resection, the amount transfused averaged 2,000 c.c., with extremes of zero in 2 cases and 4,500 c.c. in 2 cases. In comparison, in those who survived resection, the average amount of blood transfused during operation was 1,800 c.c.

Intravenous fluids other than blood administered during operation were recorded in 22 of the 24 cases where death occurred following operation. The amounts varied from zero in 4 cases to 2,000 c.c. in 1 case, the average being 600 c.c., usually glucose in distilled water.

The exact duration of the operation among those who died was recorded in 19 cases, and varied from three to nine hours, the average being five and one-half hours. The average duration of operation among those who survived was precisely the same.

Complications during operation occurred in 3 of the 24 patients who died following operation. Two of these were blood transfusion reactions. In one, the patient, who was type AB Rh positive, was given a total of 2,000 c.c. of blood which was type AB Rh positive, Group O Rh positive, and Group O Rh negative. A hemorrhagic diathesis developed with bleeding from all wound surfaces, and death occurred in the operating room. In another, incompatible blood was given, obviously through error. In another, death occurred three and one-half hours after an operation lasting five and one-half hours as a result of a course of events interpreted as being due to a vago-vagal reflex and anoxia.

POSTOPERATIVE THERAPY

Postoperative therapy consisted of intravenous alimentation, antibiotics, and constant gastric drainage by suction via a transnasal Levin tube. In general, a total of 3,000 c.c. of fluids was given daily, containing glucose, amino acids and vitamins. In retrospect, this was excessive in some patients, although it was difficult to ascertain the exact number. The antibiotics used most commonly were penicillin and streptomycin. In the few patients operated on prior to their introduction, the sulfonamides were used. The Levin tube was removed generally two or three days following operation.

Esophagograms using Lipiodol were made generally four to six days following operation. If there was no extravasation of oil, oral intake was allowed immediately in increasing amounts with a corresponding decline and abandonment of the intravenous alimentation.

Other than in the 5 patients who died within eight hours following resection, the average duration of life following resection in the remaining 19 cases was 11 days, with extremes of 2 days and 31 days.

LONG-TERM RESULTS

In addition to presenting the dire results of the operative treatment of the cases of primary carcinoma of the esophagus in this series, a word should be said about the equally dire results in the entire group. Of the 210 cases, not including one case in which treatment had not been begun at the time of this compilation, there are only 10 patients living. Three of the 10 patients were treated by resection, having esophagogastrostomy performed in the neck, at the level of the arch of the aorta, and below the arch of the aorta in one case each. The patient with the intracervical anastomosis has now survived two years and seven months, with ability to eat and swallow normally throughout but with known residual carcinoma in the lower trachea and both main bronchi. She has been treated recently by radiation therapy with a dramatic improvement in her dyspnea to such an extent that she has been able to resume her usual occupation as a domestic servant. The patient with the juxta-aortic anastomosis has now survived five years with no evidence of persistent or recurrent carcinoma to date.

Seven of the 10 surviving patients have had radiation therapy, the longest surviving patient having completed treatment only eleven months ago. However, only 3 of the 7 have a chance of a good result. The remaining 4 patients have uncontrolled primary lesions, and each has a gastrostomy for feeding purposes.

DISCUSSION

As the problem of the surgical treatment of epidermoid carcinoma of the esophagus stands at present, the operative mortality must be reduced to acceptable levels. Otherwise, serious consideration must be given to the abandonment of the procedure of esophageal resection with restoration of the continuity of the alimentary tract in a single-stage operation. The possible and probable exception to this statement is in the treatment of epidermoid carcinoma in the terminal fourth of the thoracic esophagus, in which cases we believe that opera-

tion is still the preferable method of treatment. The statement applies in particular to the treatment of lesions which require superior mediastinal or intracervical anastomosis after their resection. The results reported with radiation therapy[3, 5, 7, 8, 13] and plastic tube replacement[1] serve to augment this conclusion.

An obvious need for the reduction of operative mortality is a method for the conversion of these extremely malnourished patients from a catabolic phase into a prolonged anabolic phase. At times the catabolic phase is striking even in the absence of a high degree of esophageal obstruction. The provision of calories which have been given to the present group of patients in quantities of 3,500 to 4,500 per day in the preoperative period has not resulted in the desired anabolism. What other factors are concerned in the continuation of catabolic processes in the presence of adequate caloric intake should be investigated. The duration of the preoperative preparation may be a factor of considerable importance. Prolonging this period may result in the patient's conversion to an anabolic phase but this is doubted. The possible continued growth of the neoplasm during the preoperative period serves to limit its duration, unless therapeutic measures were being directed toward the neoplasm itself. Perhaps this could be achieved by radiation therapy during the interval of preparation for operation, combining the two methods of treatment. The use of hormonal therapy[2] in patients who fail to revert from catabolic metabolism may help to lessen the operative mortality.

Another need is revision of the operative procedure as we have performed it in the majority of cases. The approach through the left chest, with transdiaphragmatic mobilization of the stomach, is too time-consuming. The utilization of plastic tube replacement, or of simultaneous midline abdominal and right thoracic incisions by two teams may be the answer to this portion of the problem. The present method of anastomosis of the esophagus and the stomach needs to be reviewed. The largest single cause of death in this group of patients was disruption of the suture line at the anastomosis with resultant esophagopleural fistula and empyema. Whether this disruption results from local technical causes or general causes associated with the depletion of the patient by starvation has not been determined. Both of these causes may be implicated in each case, but other alimentary canal resections and anastomoses in depleted patients are not associated with such forbidding mortality. Perhaps tunneling the esophagus into the stomach by suturing the fundus of the stomach around the terminal end of the remaining esophagus would be of aid in securing firmer union between the two organs. It might be of value to mobilize all or a portion of the omentum from the transverse colon, so that the omentum may be used to cover the anastomotic line. These procedures will require further investigation.

Another need is a change in the criteria for operability and resectability. More attention must be paid to the presence of associated diseases, hypoproteinemia, and to lack of weight gain during intensive restorative therapy, despite apparent improvement in strength and general appearance. Actually we changed our criteria two years ago, and since then have elected to use x-ray therapy instead of resection in some who would have been considered formerly to be operable and possibly resectable.

It is believed that overtransfusion of blood and overhydration during the operative and immediate postoperative periods have contributed to the fatal outcome in more cases than in which they are reported as being the primary cause of death. Replacement of blood should not exceed the loss in order that the number of transfusions may be kept at a minimum, particularly from the standpoint of reduction of the incidence of transfusion reactions, the chances of which increase geometrically with each of multiple transfusions.

SUMMARY

1. An analysis of 210 patients with primary epidermoid carcinoma of the esophagus is presented, with particular regard to a critical review of the causes of death in patients treated by resection.

2. The mortality rates for resections of the thoracic esophagus, with and without restoration of continuity of the alimentary tract, are presented.

3. There were 43 cases treated by resection of the esophagus, with an average operative mortality of 56 per cent.

4. The causes of death are enumerated, the most frequent being failure of healing of the anastomosis with esophagopleural fistula and empyema.

5. The causes of death have been analyzed from the standpoints of the status of the patients on admission, the preoperative therapy and its duration, the operative technique, and postoperative therapy.

6. The operative mortality must be reduced in order to justify the continued use of resection by the methods described, especially in the treatment of lesions in the region of the arch of the aorta.

7. Considerations on the needs for the reduction in operative mortality are presented.

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THE SURGICAL TREATMENT OF CHRONIC PERICARDIAL EFFUSION AND CARDIAC TAMPONADE

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THE operative treatment of patients with inflammatory lesions of the pericardium has been generally limited in application, during recent years, to those patients who were suffering from a constrictive type of pericarditis. Relatively few references appear in the current literature by authors who advocate pericardiectomy during the effusive stage of pericarditis, particularly of the nonsuppurative type. It may be of interest to recall that as early as 1819 Romero[1] had operated on three patients with effusive pericarditis, two of whom survived. The operation consisted of an incision made through the left fourth interspace near the sternum, the distended pericardium was felt with the finger, picked up with forceps, and cut with scissors. A number of other successful cases was subsequently reported, but due to the influence of Dieulafoy,[2] in 1873, pericardicentesis replaced incision and drainage as the method of choice in the treatment of pericardial effusion. This influence still prevails. Today the treatment of pericarditis with effusion is usually carried out by the internist, who commonly employs repeated pericardicenteses to decompress the pericardial cavity. While this regimen is usually satisfactory, we believe that it may have the following disadvantages: (1) Pericardicentesis has, on occasion, resulted in fatal hemorrhage. (2) Cardiac tamponade usually is relieved only temporarily, and prolonged tamponade may result in serious myocardial, hepatic, and pulmonary damage. (3) The longer the infection in the pericardial cavity persists, the greater is the danger of progression to the constrictive phase of pericarditis. In the series of Heuer and Stewart,[5] 27 per cent of patients with constrictive pericarditis had previous pericardial effusion.

Because of these disadvantages and because pericardiectomy is much more easily performed during the effusive rather than the constrictive stage of pericarditis, we believe that the recent suggestion by Holman[3] of early pericardiectomy has great merit and that the operation is indicated, not only for patients with acute tuberculous pericarditis, as recommended by him, but also for some patients with idiopathic pericarditis. An important contribution which has influenced us in coming to this decision is that of Barker and Johnson,[4] who recently emphasized the fact that nontuberculous pericarditis with effusion is a chronic disease more frequently than is generally appreciated. One of their patients suffered from a pericardial effusion for six years before the lesion progressed to the constrictive stage.

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We have had an opportunity to observe the results of elective pericardiectomy performed during the stage of effusive pericarditis in four patients and also to follow the courses of two other patients from the stage of effusion to eventual constrictive pericarditis, which required a technically more difficult operation. In the latter patients, symptoms and signs of cardiac tamponade persisted unnecessarily for several years while the stage of constriction developed. We believe that both patients would have profited from an earlier pericardiectomy. One patient had tuberculous pericarditis, but in five patients the etiology was undetermined. The ages of the patients ranged from 34 to 67 years. The predominating symptom in all patients was severe dyspnea. Some or all of the following signs of cardiac tamponade were present in each case before operation: hepatomegaly, ascites, low pulse pressure, low blood pressures, elevated venous pressure, prolonged circulation time, dependent edema, and low voltage electrocardiographic patterns. The apparent duration of the disease prior to operation averaged seventeen months. Five of the six patients had moderate fevers and received streptomycin and PAS therapy for at least two weeks prior to operation.

CASE SUMMARIES

CASE 1.—W. L., K.C.H. No. 21514-51, a 41-year-old tailor, was admitted to the Kings County Hospital for the first time on May 3, 1951, complaining of cough and night sweats of three weeks' duration. The temperature was 102.5° F., the blood pressure was 140/80; the pulse was 80; and the respiration was 24. Physical examination revealed moist râles in the left lung. A roentgenogram of the chest revealed a water-bottle configuration suggesting pericardial effusion (Fig. 1). A kymogram showed a decrease in amplitude of cardiac pulsations. The blood Mazzini, heterophile agglutination test, cold agglutinins, cephalin flocculation, and cholesterol determinations were all within normal limits. Two smears of the sputum for acid-fast bacilli were negative. The patient was discharged on June 27, 1951, with a diagnosis of bronchial pneumonia and pericarditis with effusion. He was admitted for the second time on Sept. 28, 1951. He complained of a cough productive of a moderate amount of whitish sputum and dyspnea which had been present since his previous discharge. He had been vomiting for one week. Physical examination revealed a large area of cardiac dullness extending to the left midaxillary line, sacral and ankle edema, and hepatomegaly. The blood count was normal except for an 8 per cent basophilia. The venous pressure was 180 mm. of water and the circulation time, with Decholin, was 17 seconds. Kymography revealed no visible excursion of the left side of the heart. On September 29 a pericardicentesis was performed with the removal of 300 c.c. of straw-colored fluid. Culture of the fluid for acid-fast organisms was negative. Urine cultures also were negative. Blood chemistries, including urea, sugar, cephalin flocculation, phosphorus, and alkaline phosphatase, were within normal limits. The albumin was 3.6 Gm., and the globulin was 2.5 Gm. Low voltage QRS complexes and flattened T waves were found in the electrocardiogram. The tuberculin 1-1,000 was positive. A ballistocardiogram was negative. On October 5 and October 12, 450 c.c. and 350 c.c., respectively, of serosanguineous fluid was removed. The patient failed to improve, although he received dihydrostreptomycin for one month. On Nov. 24, 1951, the left chest was entered anterolaterally at the level of the fourth left rib and cartilage. The pericardium was 3 mm. in thickness and cartilaginous in consistency. The heart was not enlarged. An anterolateral segment of parietal pericardium 7 by 8 cm. was resected. The pleural space was drained and the chest closed. The patient's postoperative course was satisfactory. The pathologic report indicated a chronic fibrosing pericarditis, probably granulomatous. No carcinoma cells were found in the pericardial fluid. Gradual clearing of the postoperative

pleural reaction on the left side occurred. The patient was last seen in April, 1954, at which time he occasionally had mild swelling of his ankles at the end of the day, but was otherwise well and attended work regularly. The roentgenogram of the chest was normal (Fig. 2).

Fig. 1.

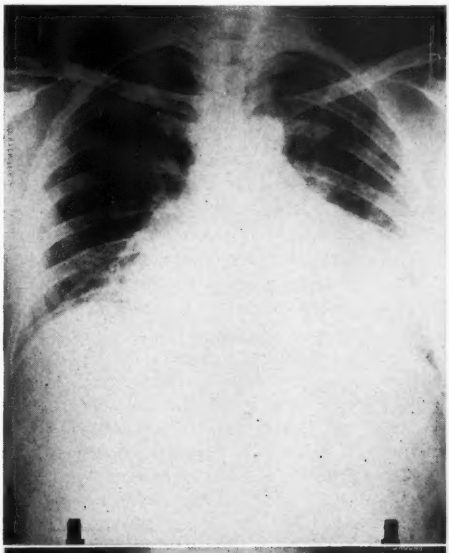


Fig. 2.

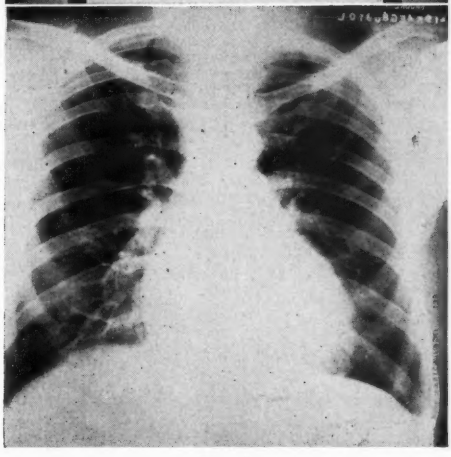


Fig. 1.—Case 1. A roentgenogram of the chest taken prior to operation. A large pericardial effusion, and some basal, pleural, and pulmonary congestion are present.

Fig. 2.—Case 1. A roentgenogram taken 29 months after operation. There is no evidence of pericardial or pleural effusion.

Comment.—This patient had a prompt, favorable, and sustained response following pericardiectomy for idiopathic pericarditis with effusion. The clinical course and the operative findings suggest that further temporization in treatment would have been unwise.

CASE 2.—M. W., B. H. No. 153785, a 43-year-old Negro woman, was admitted to the Brooklyn Hospital on May 27, 1952. In February, 1952, the patient had developed severe dyspnea. She had previously been admitted to another hospital, where it had been necessary during the next ten weeks to perform pericardicenteses on seven occasions. She complained of swelling of the ankles, and cough, as well as a sensation of pressure in the left chest. There was no history of rheumatic fever. Except for pneumonia at the ages of 20 and 31, there was no significant past history.

The patient's father and mother had died of heart disease at 40 and 39 years of age, respectively.

Physical Examination.—The patient was a dyspneic, orthopneic Negro woman, weighing 154½ pounds and measuring 5'3" in height. She appeared chronically ill. The pulse was 80, the blood pressure 150/120, temperature, 99° F., respiration 14.

The neck veins were distended. Motion of the left hemithorax was limited, and there were dullness to percussion and diminished to absent breath sounds over the left chest. The cardiac silhouette was greatly enlarged to percussion with regular sinus rhythm and no murmurs. The heart sounds were loud and of good quality. The liver was enlarged to three fingerbreadths below the costal margin. Ascites and ankle edema were prominent.

A diagnosis of pericardial effusion was made. On May 28, 1952, a pericardial tap was performed and 550 c.c. of dark red fluid was removed. On May 30 the venous pressure was 178 mm. of water, which was elevated to 245 mm. with right upper quadrant pressure and later returned to 182 mm. of water. The circulation time, using Decholin, was 11 seconds. On June 3 a second pericardial tap yielded 450 c.c. of bloody fluid. On June 5 the venous pressure was 94 mm. of water with right upper quadrant pressure at 102 mm. The circulation time was 12 seconds. On June 6, 1952, 950 c.c. of grossly bloody fluid was removed from the pericardial sac. On June 7 the liver was two fingerbreadths below the right costal margin. The neck veins were still distended. On June 15 a loud pericardial friction rub could be heard over the pericardium. The edge of the liver was palpated 4 cm. below the costal margin. A pericardial tap was unsuccessfully attempted on June 15.

An electrocardiogram revealed QRS complexes and T waves of very low voltage in all leads. These complexes, particularly the T waves, became larger following removal of pericardial fluid. Five examinations of the pericardial fluid, including one culture, did not reveal acid-fast bacilli.

The total protein was 5 Gm. per 100 c.c,; the albumin was 2.4. and globulin 2.6. Plasma chlorides were 102 meq. The blood count was normal except for anemia, the hemoglobin being 65 per cent and the red cells 2,940,000. The urine analysis was normal. The erythrocyte sedimentation rate was 16 and 51 mm. on May 31, 1952, and 31 and 71 mm. on June 9, 1952, the readings being taken at half-hour intervals. The blood sodium was 140 meq.; potassium was 4.03 meq. Blood urea, creatinine, and sugar values were within normal limits.

Roentgenograms of the chest revealed a very striking enlargement of the cardiac silhouette, typical of pericardial effusion (Fig. 3). Air was instilled into the pericardial sac revealing an apparently normal-sized heart, although the cardiophrenic angles could not be visualized (Fig. 4).

The patient received Mercuhydrin on five occasions, was digitalized prior to operation, and received 1 Gm. of streptomycin and 8 Gm. of para-aminosalicylic acid daily, starting on June 2, and continuing until July 7.

On June 19, 1952, an extensive parietal pericardiectomy was performed. The pericardium measured approximately 3 to 4 mm. of thickness. No evidence of constriction of the heart was found, but approximately 500 c.c. of fluid containing some fibrinous clots was aspirated from the pericardial sac. Cytologic examination of the pericardial fluid showed no evidence of neoplastic disease. Pathologic examination of the parietal pericardium, which measured 20 by 12 cm., revealed a chronic inflammatory process characterized by perivascular accumulations of lymphocytes. Some old hemorrhage and partially hyalinized fibrin were also present. The pathologic diagnosis was chronic fibrinous pericarditis.

Except for a small collection of fluid in the left pleural cavity, which subsequently disappeared, and a left basal pleuritis, the patient had an uneventful postoperative course. Immediately following operation, she was able to breathe much more comfortably and generally felt greatly improved, being discharged on the twentieth day after operation. The patient was last seen on Dec. 11, 1953, at which time she was feeling exceptionally well. She was

Fig. 3.

Fig. 4.

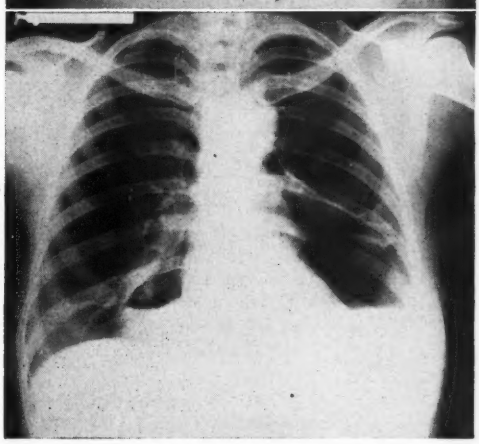


Fig. 3.—Case 2. This roentgenogram illustrates the great size of the pericardial effusion prior to operation.

Fig. 4.—Case 2. Air has been instilled in the pericardial sac. The heart, although incompletely visualized, does not appear to be enlarged.

able to sleep flat in bed and had no dyspnea, orthopnea, or ankle edema. Her appetite had improved so greatly that she had gained 50 pounds since leaving the hospital, without any evidence of edema. She was placed on a weight-reduction diet. The heart and lungs were normal on physical examination. A roentgenogram of the chest at this time revealed only the residuum of the previous pleuritis at the left base (Fig. 5).

Comment.—This patient had dramatic relief immediately following parietal pericardiectomy for massive idiopathic pericarditis with effusion. A vigorous medical regimen, including many pericardicenteses, had failed previously to control the disease. The operation was technically easy at this stage.

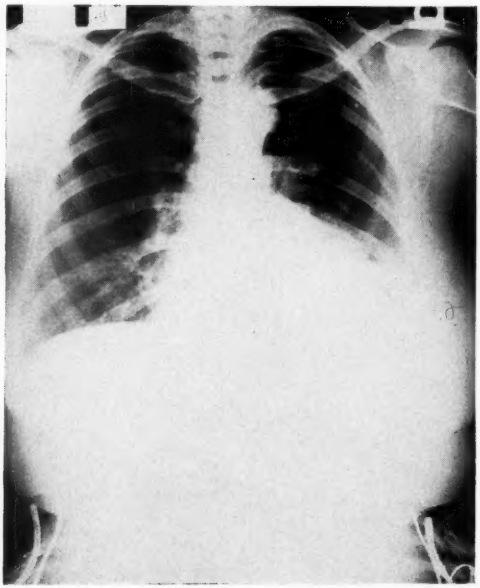


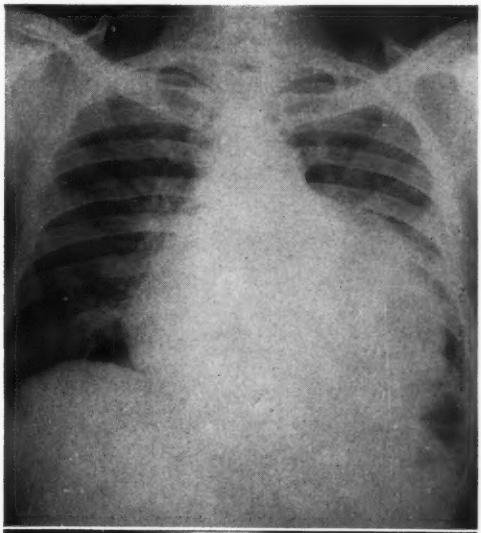
Fig. 5.—Case 2. A roentgenogram taken 18 months following an extensive parietal pericardiectomy. The heart and lungs are normal. There is some residual pleuritis at the left base.

Case 3.—H. W., K. C. H. No. 12732, a 48-year-old Negro, was admitted to the Kings County Hospital on March 12, 1953. In January, 1953, the patient had developed a productive cough and had suffered from epigastric pain and anorexia relieved by the administration of antacids. In March, 1953, he had become short of breath while climbing only one flight of stairs. He had never been dyspneic before in his life, and there were no other cardiac symptoms. He had lost 10 pounds during the previous three months. There was no family history of pulmonary tuberculosis.

Examination revealed a middle-aged Negro with a temperature of 103° F., pulse 100, blood pressure 118/80, and respiration 30. There were slight distention of the neck veins, dullness at the right base, and râles over the left lower lobe. The cardiac silhouette by percussion was enlarged to both the left and right sides, with frequent premature ventricular contractions. The liver edge was felt two fingerbreadths below the costal margin. There was no edema of the extremities. The venous pressure was 210 mm. of water, which increased to 310 mm. with pressure on the liver. The circulation time, with Decholin, was 30 seconds. The erythrocyte sedimentation rate was 24 mm. and 60 mm. The blood count on two occasions and the urine analysis were normal. An electrocardiogram taken one week after admission showed low voltage in all standard leads with isoelectric to negative T waves. An investigation of the gastrointestinal and genitourinary tracts, including endoscopic and roentgen examinations, was negative for any abnormality. A parenchymal lesion was never detected in the roentgenogram of the chest, and the sputum studies were consistently nega-

tive for acid-fast bacilli. Roentgen examination revealed a generalized and marked enlargement of the cardiac silhouette (Fig. 6). At fluoroscopy the cardiac pulsations were diminished. A tentative diagnosis of tuberculous pericarditis with effusion was made, and on March 20, 1953, the patient was started on a regimen of streptomycin and para-aminosalicylic acid.

Fig. 6.



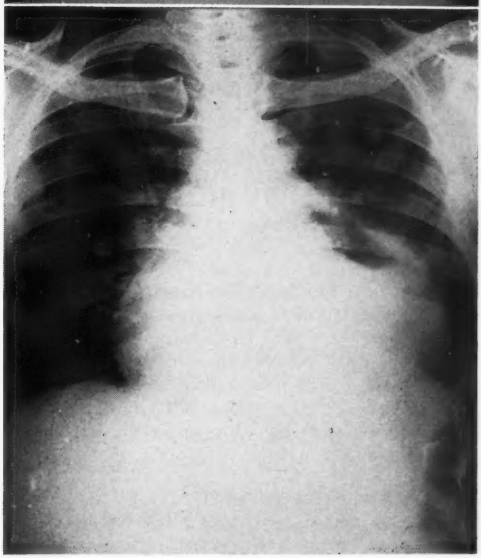


Fig. 7.

Fig. 6.—Case 3. A large pericardial effusion is present.

Fig. 7.—Case 3. Air has been instilled into the pericardial sac. A marked thickening of the parietal pericardium is present.

Within the next three weeks a total of four pericardicenteses was performed yielding a slightly turbid, yellow fluid. A smear of this fluid revealed the presence of acid-fast bacilli. A total of 2,215 c.c. was removed from the pericardial sac on these occasions, the largest amount being obtained on April 9, 1953, when 1,200 c.c. was removed. After four weeks of antibiotic therapy and repeated pericardicenteses, the fluid was still forming, and the fever was essentially unchanged. Air had been instilled into the pericardial sac following one of the pericardicenteses, revealing a marked thickening of the parietal pericardium (Fig. 7).

On April 21, 1953, operation was performed. An acute and chronic inflammatory process was found involving the parietal pericardium, which in some areas was as much as 2 cm. in thickness. A few patches of fibrinous exudate were present on the visceral pericardium. These were easily removed. There was no evidence of constriction of the heart. An extensive parietal pericardiectomy was performed. The report of the pathologist indicated tuberculous pericarditis.

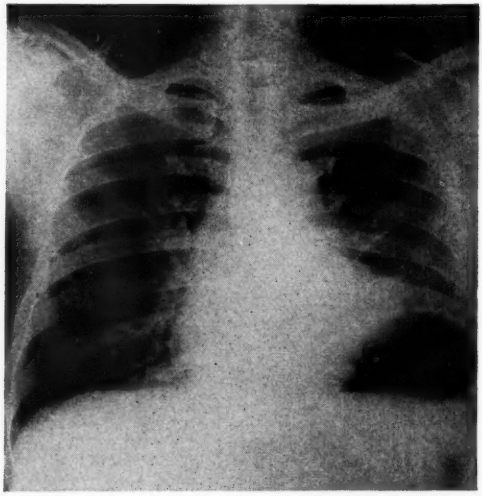


Fig. 8.—Case 3. A roentgenogram of the chest taken eight months following pericardiectomy. No abnormality is present, except for the elevated left hemidiaphragm.

Following operation, the fever gradually decreased, a normal temperature being reached on May 31, 1953, and being maintained thereafter. During this time the patient generally felt greatly improved, particularly in regard to dyspnea. By Sept. 28, 1953, the patient had gained 7 pounds without evidence of edema. On Oct. 6, 1953, the venous pressure was 70 mm. of water, which did not change with pressure in the right upper quadrant. The Decholin time was 10 seconds. At the time of discharge on Dec. 17, 1953, the patient was asymptomatic. A roentgenogram of the chest revealed only elevation of the left hemidiaphragm due to the removal of the phrenic nerve with the pericardium (Fig. 8).

Comment.—This patient had a pericardiectomy for tuberculous pericarditis as soon as the diagnosis was established, and a brief course of chemotherapy and antibiotics was administered before operation. Although the parietal pericardium was greatly thickened, it was easily removed. He has had an excellent result.

CASE 4.—J. M., K. C. H. No. 50561, a 67-year-old Negro, was admitted to the Kings County Hospital for the first time on April 15, 1952, because of edema of the ankles, and marked dyspnea. Two pericardial aspirations yielded a total of 820 c.c. of fluid which contained neither acid-fast bacilli nor tumor cells. The patient was thought to have tuberculous pericarditis and a pericardiectomy was advised, but he refused operation. During the next twenty-two months he was readmitted to the hospital on three occasions because of progressive orthopnea. He had received streptomycin, para-aminosalicyclic acid, digitalis, Mercuhydrin, and aspiration for ascites and pleural effusions. Despite this therapy his neck veins remained distended; a high venous pressure persisted, measuring from 310 to 390 mm. of saline; fluid reaccumulated in the serous cavities; the liver remained greatly enlarged; and the cardiac silhouette gradually decreased in size. This course of events strongly suggested the development of constrictive pericarditis.

The 1-100 tuberculin test was strongly positive, but repeated examination of the gastric juice, urine, pleural, and pericardial fluid by smears and culture techniques did not reveal acid-fast bacilli. The blood Kolmer was positive in 1:10 dilution. The basal metabolic rate was normal, as were the following blood determinations: cholesterol, total proteins, albumin and globulin, urea, and glucose.

In January, 1954, orthopnea had progressed to the point where the patient was unable to sleep. The vital signs at that time were: blood pressure 110/70, pulse 80, respirations 28, temperature 99° F. He periodically developed a low-grade fever ranging from 100° to 101° F. During the following month bilateral pleural effusions recurred following thoracenteses. The heart was not enlarged; its sounds were distant, and the rhythm was regular. The liver edge was five fingerbreadths below the costal margin. The vital capacity was 1,200 c.c. At fluoroscopy very little pulsation of the cardiac borders could be detected. The electrocardiogram on four occasions was characterized by low voltage QRS complexes and inverted T waves interpreted as evidence of myocardial damage.

Because of the severity of his symptoms and the need for frequent thoracenteses (Fig. 9), the patient finally agreed to operation, which was performed on Feb. 4, 1954. Typical constrictive pericarditis was found, the heart being encased in fibrous tissue which was thickest over the right and left ventricles where it measured approximately 5 mm. The scar actually extended into the superficial layers of the myocardium, necessitating a meticulous and difficult decortication. This was accomplished without incident, however, and following removal of the scar from the left and right ventricle and the base of the pulmonary artery, considerable improvement in cardiac action was noted.

The anatomic diagnosis was chronic fibrous pericarditis of undetermined etiology.

The patient had an uneventful postoperative course. Four months later, when he was seen in the clinic, his only complaint was occasional nocturnal dyspnea. His neck veins were not distended, there was no ankle edema, and the liver edge was palpable two fingerbreadths below the costal margin representing a considerable diminution in hepatomegaly. A roentgenogram of the chest revealed only residual pleural thickening (Fig. 10).

Comment.—Although a good result was obtained in this 67-year-old man, we feel that the operation would have been easier to perform when it was originally recommended during the stage of effusion. Furthermore, the immeasurable ill effects of two additional years of chronic pericarditis with cardiac tamponade would have been avoided by early operation.

CASE 5.—A. A., K. C. H. No. 10858, a 57-year-old white man, was admitted to the Kings County Hospital for the first time on June 30, 1949, because of dyspnea, cough, profuse perspiration, ankle edema, and fever of three weeks' duration. Because of a history of 35 years of alcoholism and an apparently inadequate diet, the patient was thought to have cirrhosis of the liver. A massive pericardial and bilateral pleural effusion was present (Fig. 11). Four pericardial aspirations yielded a total of 875 c.c. of blood-tinged fluid

Fig. 9.

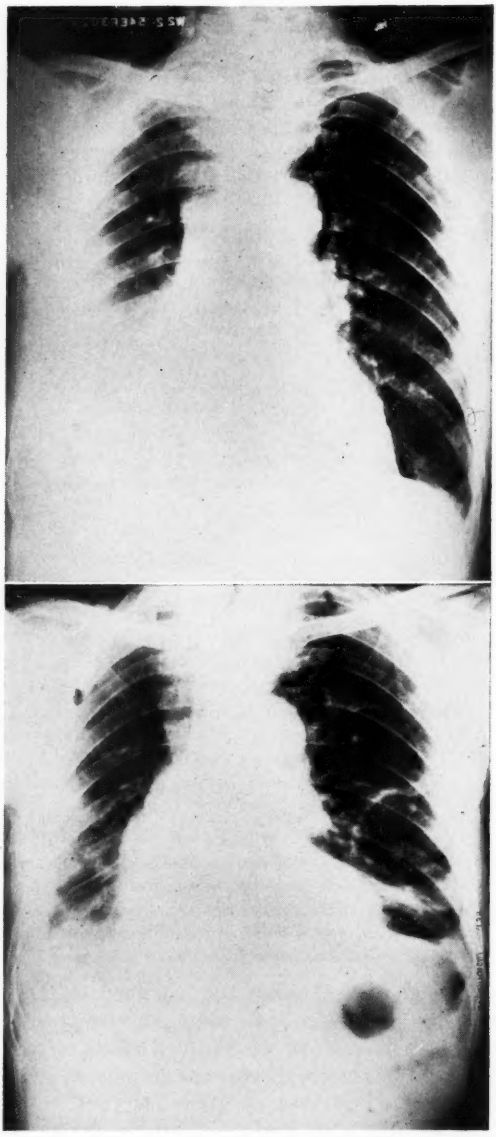


Fig. 10.

Fig. 9.—Case 4. A roentgenogram taken two days before operation illustrating the persistent right pleural effusion.

Fig. 10.—Case 4. Two months following pericardiectomy the only abnormality in the roentgenogram is bilateral pleural scars from the previous prolonged pleural effusions.

following which the cardiac silhouette decreased to a slight degree (Fig. 12). A kymogram taken at this time revealed pulsations of good amplitude despite the presence of fluid (Fig. 13). Marked ascites was present requiring the removal of as much as 6,500 c.c. of straw-colored fluid on one occasion. The venous pressure was 330 mm. of saline; the circulation time, with Decholin, was 21 seconds; the neck veins were engorged; and the liver was enlarged 8 cm. below the costal margin. After repeated paracenteses, the patient was discharged

Fig. 11.

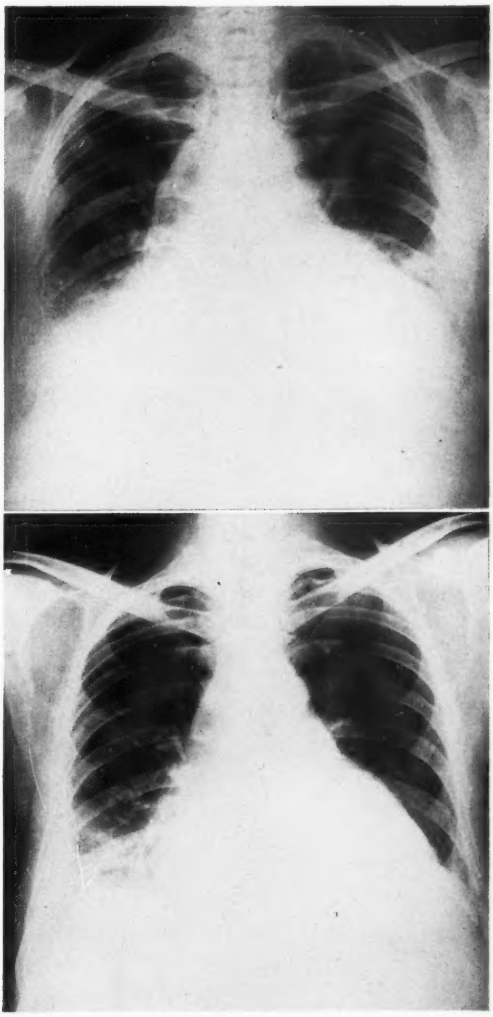


Fig. 12.

Fig. 11.—Case 5. Massive pericardial and bilateral pleural effusion is present on July 22, 1949.

Fig. 12.—Case 5. A roentgenogram taken one month later (Aug. 19, 1949). There has been some decrease in pericardial and pleural effusion.

Fig. 13.

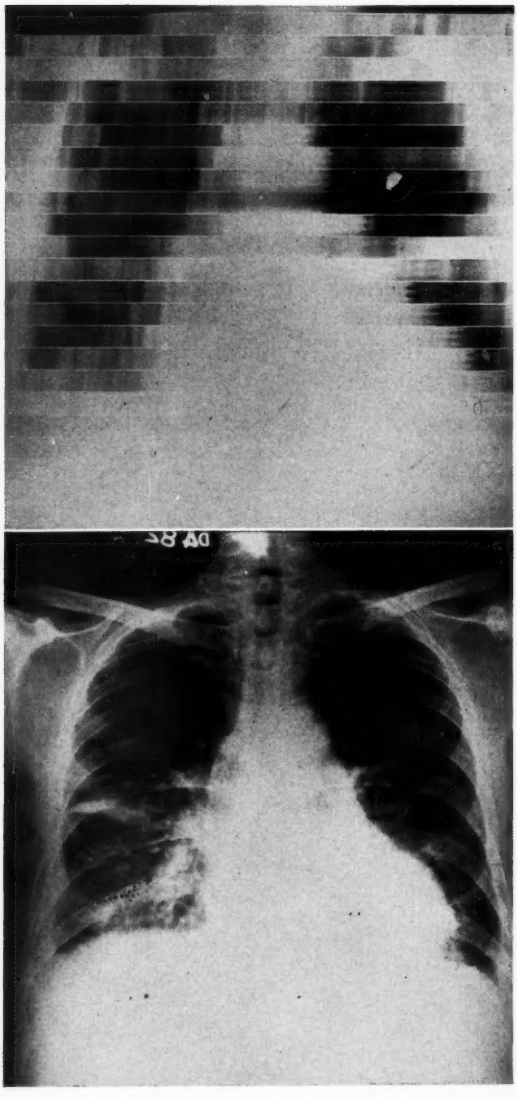


Fig. 14.

Fig. 13.—Case 5. A kymogram taken in 1949 during the stage of pericarditis with effusion. Note the peaked contours along the left lateral cardiac border indicating adequate diastolic filling and systolic ejection.

Fig. 14.—Case 5. In 1952, three years later, the heart is normal in size but there is still fluid in the right costophrenic angle and in the oblique fissure.

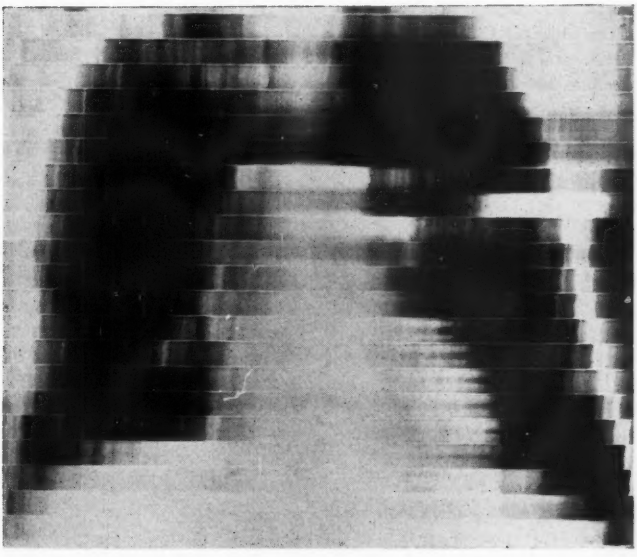


Fig. 15.—Case 5. A kymogram taken in 1954 during the stage of constrictive pericarditis. The superficial plateaulike contours along the left lateral cardiac border indicate delayed prolonged diastolic filling and systolic ejection of the ventricles.

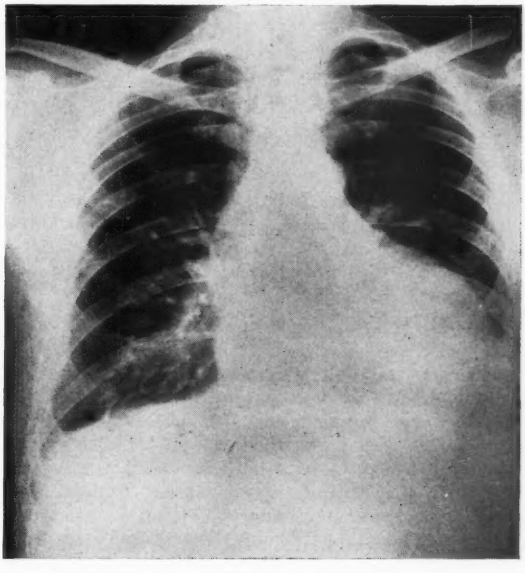


Fig. 16.—Case 5. A roentgenogram of the chest two months following pericardiectomy.

somewhat improved. He was admitted for a second time on Jan. 22, 1952, because of swelling of the abdomen, scrotum, and ankles. The total blood proteins were 5 Gm.; the albumin was 3.3 and the globulin 1.7. Following abdominal paracenteses, he was discharged as improved six days later. It should be noted that although there were still signs of cardiac tamponade on this admission, the heart was now normal in size (Fig. 14).

The most recent entry into the hospital was March 11, 1954, when he again complained of marked edema of the scrotum, penis, and abdomen. Physical examination revealed a temperature of 99.6° F., pulse was 80, respiration 20, and blood pressure 110/80. The neck veins were distended; the abdomen was markedly enlarged due to ascites; and an advanced degree of edema of the penis and scrotum was present. The venous pressure was 234 mm. of saline, and the circulation time, with Decholin, was 20 seconds. The heart was small, and the kymogram was interpreted as evidence of constrictive pericarditis (Fig. 15). A giant A wave in the jugular pulse tracings, faint heart sounds, and the previous existence of a pericardial effusion constituted substantiating evidence of this diagnosis.

On a low salt diet, Mercuhydrin, and abdominal paracenteses, the patient's weight was reduced from 182 to 149 pounds within one month. On April 9, 1954, a pericardiectomy was performed. The operative findings included adhesions between the left lower lobe and the pericardium, and complete obliteration of the pericardial cavity by a constrictive pericarditis. The scarred pericardium measured about 4 mm. in thickness, and after removal of it from the surface of the left and right ventricles and the base of the pulmonary artery, movement of the heart was greatly increased. During operation the heart was extremely irritable, becoming irregular and alternately slow and very rapid within the slightest manipulation. The patient withstood the opeation very well, however, and had a relatively uncomplicated postoperative course. On May 10, 1954, he had ceased to accumulate peritoneal, pleural, and peripheral fluid and was feeling generally greatly improved. The pathologic report revealed acute and chronic nonspecific pericarditis. When examined two months after operation, the patient was asymptomatic. There was no ascites or edema of the ankles or distention of the neck veins. The roentgenogram of the chest was essentially normal (Fig. 16).

Comment.—This patient was treated conservatively for pericarditis with effusion. His symptoms persisted, and three years later signs of constriction were present but not recognized. The signs of advanced cardiac tamponade were eventually relieved by pericardiectomy performed five years after the pericardial effusion was first detected. It would appear, in retrospect, that an earlier operation was indicated.

CASE 6.—T. McD., K.C.H. No. 10135-51, a 45-year-old white man, was admitted to the Kings County Hospital on six occasions between 1949 and 1951 for congestive heart failure. On Dec. 23, 1951, he complained of severe dyspnea and had recently had an arterial vascular occlusion of the right foot from which he had recovered spontaneously. He had received frequent mercurial injections and digitalis.

Physical Examinations.—The blood pressure was 120/88, pulse 88, respiration 20, and temperature 101° F. The lungs were clear. The heart was enlarged to the left anterior axillary line, and a gallop rhythm was present. There was no edema. The right foot was dusky and paler than the left. The blood count and sedimentation rates were normal. The circulation time, with Decholin, was 22 seconds. An electrocardiogram revealed low voltage QRS and T waves, with QS waves present in Leads II, III, and V_6. This was interpreted as indicating myocardial lesions and pericardial effusion. The roentgenogram of the chest revealed an infiltrate in the right second interspace with bilateral pleural effusion and a cardiac silhouette which was moderately enlarged (Fig. 17). Tomograms of the heart revealed no calcific deposits. There were diminished pulsations along the left border of the heart by kymography and fluoroscopy. A second Decholin time was 28 seconds. A tuberculin test was positive in 1-10,000. The ballistocardiogram was normal. Blood sugar and urea were normal. Blood cultures were negative. The basal metabolic rate and measurement of

Fig. 17.

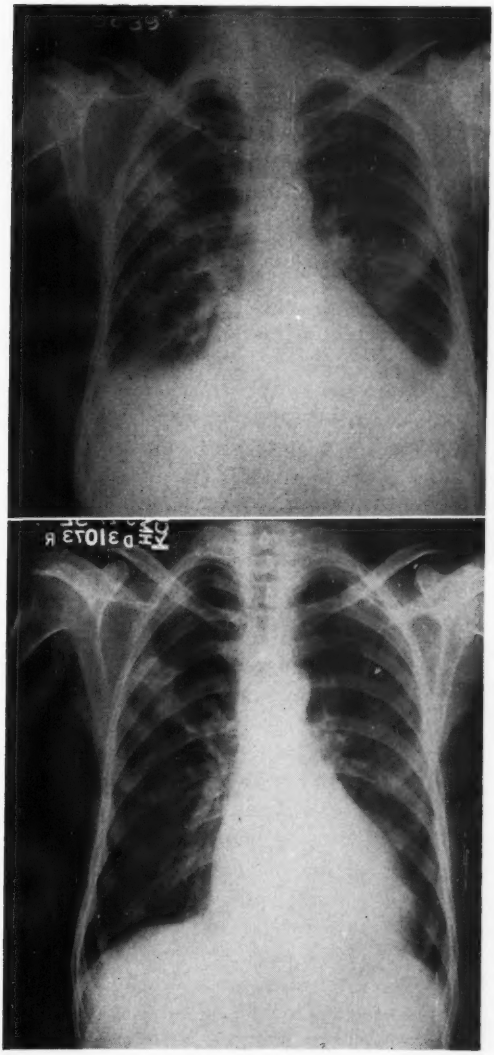


Fig. 18.

Fig. 17.—Case 6. Pericardial and bilateral pleural effusion is noted prior to operation. There are also bilateral pulmonary infiltrates.

Fig. 18.—Case 6. Two months after pericardiectomy the pleural effusion has disappeared; the pulmonary infiltrates, as well as the cardiac silhouette, are considerably smaller.

I^{131} and creatine determinations were all within normal limits. The blood Wassermann test was negative. Numerous cultures of the sputum, urine, and gastric juice were negative for acid-fast organisms.

The patient continued to have episodes of decompensation, engorgement of the neck veins, bilateral moist râles, enlargement of the liver, and dependent edema. Blood pressure persisted at about 90/80. A two-week course of streptomycin and PAS was given, and on April 1, 1952, the patient was operated on under endotracheal anesthesia. The sternum was split and the pericardial cavity was found to be tensely filled with clear, watery fluid. No adhesions were present, but several small fibrotic patches were seen on the surface of the myocardium. The operative diagnosis was general myocardial degeneration. A large portion of the left anterior parietal pericardium was removed and the sternum was approximated. A thoracotomy drainage tube was inserted in the sixth interspace posteriorly. The pathologic diagnosis was subacute pericarditis.

The patient developed a superficial wound infection which healed satisfactorily. Eight weeks after operation the cardiac silhouette and the pulmonary infiltrate were smaller (Fig. 18). It was noted that during convalescence, both in the hospital and later in the clinic, his dyspnea was greatly relieved. He felt much improved and had returned to work. Two years after operation he died unexpectedly at home. An autopsy was not performed.

Comment.—It is not certain whether this man had pericarditis with effusion and associated myocardial degeneration with primary atypical pneumonia, as described by Godfrey,[6] or whether the pericardial effusion was a manifestation of congestive heart failure due to idiopathic myocarditis.[7] He was thought by the cardiologists to have the former syndrome. At operation, pericardial fluid was present under tension, and dyspnea was greatly relieved following a parietal pericardiectomy. This relief of symptoms continued until the time of his fatal attack.

DISCUSSION

We believe that the surgical treatment of patients with pericarditis should be formulated on the basis of a knowledge of the pathogenesis of the disease. Progression of pericarditis with effusion to the stage of constriction is not uncommon. Rigid distinctions between the stages of adhesive pericarditis (accretio cordis) and constrictive pericarditis (concretio cordis) may be misleading according to Moschcowitz,[8] who believes that adhesive pericarditis is simply the earliest stage of constriction.

If these concepts concerning the pathogenesis are valid, it would appear these are additional reasons why pericardiectomy should be performed in selected cases much sooner in the course of the disease, ideally during the stage of effusion. We recommend the early operation in both the tuberculous and idiopathic types of pericarditis whenever a prompt remission in constitutional symptoms and disappearance of the fluid do not occur with conservative therapy. Any patient with an appreciably thickened parietal pericardium in the presence of effusion should likewise have pericardiectomy. We have not employed this operation during the effusive stage of rheumatic pericarditis for fear of the presence of active carditis.

We prefer resection of the pericardium rather than pericardiostomy for the following reasons: (1) It provides better drainage of the pericardial fluid. It is well known[9] that the pericardial sac, because of its configuration, is not

anatomically suited for complete, dependent drainage. (2) The problem of sealing over of the pericardial stoma is eliminated. (3) Pericardiectomy removes a part or all of the focus of infection. (4) Complete visualization of the visceral pericardium is obtained, and resection of this layer can then be performed if such action seems appropriate to the surgeon.

SUMMARY AND CONCLUSIONS

1. Six patients originally having pericarditis with effusion are reported. In five patients the etiologic agent was undetermined; in one patient it was tuberculosis.

2. All patients underwent pericardiectomy, four during the stage of effusion and two during the stage of constriction.

3. All patients had signs of cardiac tamponade during the stage of effusion and at the time of operation.

4. Pericardiectomy brought prompt relief of cardiac tamponade and striking general improvement in all patients. One patient died unexpectedly two years after operation of undetermined causes after previously feeling well.

5. Pericardiectomy is recommended during the stage of effusion in selected patients with tuberculous and idiopathic pericarditis. Reasons for this have been discussed.

We wish gratefully to acknowledge the counsel and assistance of Dr. William Dock, who has pointed out that the coronary arteries, lying in the epicardium, undergo narrowing or occlusion if the inflammatory process persists for a long time, and that healing of the pericarditis may be followed by permanent vascular damage. Dr. Dock, therefore, has consistently urged early intervention in cases of chronic effusion with tamponade and tuberculous pericarditis with early evidence of cardiac embarrassment.

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EXTRAPLEURAL PROSTHESIS CONCOMITANT WITH PULMONARY RESECTION FOR TUBERCULOSIS

Preliminary Report of 110 Cases

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AFTER a lobectomy, if preventive measures are not immediately taken, the space that has been created in the hemithorax is filled either by an adjustment of the remaining lung tissue or by deviation of the mediastinum. This results in an overdistention of lung tissue and presents two major hazards: first, reactivation of quiescent lesions through traumatic expansion; and second, emphysema, with its consequent reduction of alveolar function. To prevent these complications such procedures have been advocated as immediate thoracoplasty, pneumothorax, pneumoperitoneum, and phrenic interruption.[1, 2]

We have treated a series of 110 patients since December, 1950, by combining the lobectomy with a tailoring pleuroplasty followed by an extrapleural prosthesis. This experience leads us to believe that complications can be prevented fully as well by this method as by others, and that this method offers a wide range of benefits otherwise unobtainable.

INDICATIONS FOR PLEUROPLASTY

All the indications for performance of pleuroplasty are centered upon the problem of preventing overdistention of the ipsilateral or contralateral pulmonary tissues. The overdistention is prevented only if collapse is instituted immediately after the lobectomy. If, on the other hand, collapse is postponed and the remaining pulmonary tissue is allowed to expand for several weeks postoperatively, collapse will then be of little value. The harmful effects of overdistention will have already occurred.

Collapse concurrent with pulmonary resection is indicated by the presence of any one of the following conditions: (1) radiologic evidence of tuberculosis in the contralateral lung; (2) removal of the apical segments of the lower or middle lobe as well as removal of the upper lobe; (3) presence in the ipsilateral lung of many small, calciferous, and apparently quiescent lesions; (4) a lower lobe resection in which pneumoperitoneum cannot be instituted because of inflammatory changes; (5) inability of the remaining lobe, or lobes, to fill the hemithorax without overdistending. Inability is indicated: (a) when the lobes are extremely small but are free of palpable disease, (b) when multiple wedge or segmental resections of small lesions in the lower lobe have been performed, (c) when the remaining lobes show fibrosis from a burned-out tuberculosis, or (d) when the lungs are already emphysematous, a condition frequently found among older patients.

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Protective collapse is not necessary when localized disease, although present, is without palpable involvement of the remaining lung tissue. Nor is collapse necessary when the resected lobe is small and is contracted, and other lung tissue has already compensated. On the whole, however, we believe immediate collapse to be advisable. Jones and Robinson,[1] for instance, have cited data which show that late complications are reduced when a thoracoplasty is performed concomitantly with resection.

ADVANTAGES OF CONCOMITANT LOBECTOMY AND EXTRAPLEURAL PROSTHESIS

In our experience, extrapleural prosthesis performed at the time of the pulmonary resection shares the advantages but not the disadvantages of combined lobectomy and thoracoplasty. It is true that either combination provides effective protection against those complications that result from postoperative overdistention of the remaining lung tissue. Either combination accomplishes in a single operation what is usually done in two or more stages. However, when compared to the extrapleural prosthesis used in the present series, thoracoplasty represents a far more formidable procedure for the surgeon, while for the patient it is more deforming.

Extrapleural prosthesis preserves the intact thoracic wall and maintains the wall's normal respiratory function. Paradoxical motion does not occur as it so often does after thoracoplasty.

Less blood is lost in extrapleural dissection than in thoracoplasty—a fact which assumes considerable importance when the lobectomy is performed concurrently.

The space left by the lobectomy can be filled more accurately by a tailoring pleuroplasty than it can be by a thoracoplasty.

Disturbance to the shoulder girdle is reduced by extrapleural prosthesis.

Because of the selective prosthetic collapse, ventilation of the remaining ipsilateral lung tissue is more complete than ventilation after other methods of collapse—a matter of special importance during the immediate and the late postoperative periods.

The time required to perform an extrapleural dissection concomitantly with lobectomy is less than is required by the lobectomy-thoracoplasty operation.

Lobectomy with extrapleural prosthesis is a combination well suited to that group of older tuberculous patients in whom the clinical picture is complicated by preoperative emphysema. By virtue of its shorter operating time, shorter incision, and lowered blood loss, the combined operation is also more suitable for poor-risk patients.

Combining the two procedures into one reduces two-operation morbidity.

Since the operation is a combined procedure, financial costs to the patient are reduced.

SURGICAL TECHNIQUE

The usual posterolateral incision is made for a pulmonary resection. The opening in the chest wall is effected either through an intercostal space or by the removal of a segment of rib. If an appraisal of the pulmonary disease in-

dicates the necessity of concomitant collapse and extrapleural prosthesis, the usual sequence is to proceed with the intrapleural freeing of the lung, accomplish the pulmonary resection, and then fashion the extrapleural pocket to fit the space.

On the other hand, development of the extrapleural pocket is done before the lobectomy whenever adhesions over the upper lobe are so dense there is a danger of fragmenting diseased lung tissue near the pleural plane. This alternate sequence, incidentally, facilitates separation of the parietal and visceral pleura since it brings the apex of the lobe down into view where a more meticulous dissection can be carried out.

Intact preservation of the pleural layers is not essential. Where there is danger of entering the lung, the surgeon need not hesitate to remove localized areas of both of the pleural layers. As a matter of fact, in some patients of our series the floor of the extrapleural pocket had as many holes as Swiss cheese. Such conditions make little difference in the end result provided the pleura forms a confining web which will retain the prosthetic spheres.

After the extrapleural pocket has been fashioned, any large spaces inadvertently made in the pleural diaphragm are closed, but smaller openings are allowed to remain for drainage. Intrapleural catheter drainage was found adequate for the clearing of both intrapleural and extrapleural spaces.

REVIEW OF CASES

The 110 patients in the series ranged in age from 7 to 65 years. A gradual trend was noted of increasing age, the resections during the period being performed on increasingly older patients. Nine per cent of the patients were over 50 years of age (Table I).

TABLE I. SEX AND AGE DISTRIBUTION OF CASES

AGE IN YEARS	CASES
7-20	10
21-30	26
31-40	39
41-50	24
51 and over	11
Male	52
Female	58

In most instances, resection was limited to the upper lobe but the series included a variety of lobal segments. For instance, in two cases of lower lobectomy, the prosthesis was localized in the costophrenic sulcus. (Table II.)

The size of the prosthesis was, of course, governed by the volume of lung tissue removed. The average prosthesis consisted of six spheres, each of which measured 1¼ inches in diameter and occupied approximately 1 cubic inch of space.

Three types of prosthesis were used. The first 17 patients in the series had an air space, developed at the time of resection, which later was converted to an oleoplombage. In one case a Lucite sponge was used. Lucite spheres were employed in the last 92 cases.

TABLE II. EXTENT OF RESECTION

	NO. OF CASES
Right upper lobe	47
Left upper lobe	33
Right upper lobe and superior segment of right lower lobe	6
Left upper lobe and superior segment of left lower lobe	3
Right upper lobe and decortication of right lower lobe	2
Left upper lobe and decortication of left lower lobe	1
Right upper lobe and wedge of right lower lobe	3
Left upper lobe and wedge of left lower lobe	4
Right upper lobe and right middle lobe	3
Posteroapical and anterior segments of left upper lobe	3
Superior segment of left lower lobe	1
Posteroapical segment of left upper lobe and superior segment of left lower lobe	2
Right lower lobe	1
Right lower lobe and wedge of right upper lobe	1

We encountered none of the major complications from prosthetic replacement that are given in some of the reports. Neither effusion nor migration of prosthetic material was encountered. Infection of the prosthetic space—except in association with bronchopleural fistulas—was encountered only in the one case of prosthesis by Avalon sponge. Complications that were met in the series are given in Table III.

TABLE III. PROSTHESES AND COMPLICATIONS

TYPE OF PROSTHESIS	NUMBER OF PATIENTS	PATIENTS WITH COMPLICATIONS	COMPLICATION	DEATHS
Air, followed by oleoplombage	17	2	Bronchopleural fistula	2
Lucite sponge	1	1	Infection of space	0
Lucite spheres	92	6	Bronchopleural fistula (3)	1
			Spread of disease (3)	0
Total	110	9		3

The five infections encountered in the series resulted from bronchopleural fistulas, and these would probably have occurred with or without prosthesis. In four of these five cases the disease was far advanced and bilateral. All five were difficult resections. Two required lobectomy plus decortication and had many small bronchopleural fistulas present on closure. Two others required segmental resections of the superior division of the lower lobe in addition to upper lobectomies. The fifth case was technically a relatively easy case in which an oil plombage was used, the patient developing the fistula two and one-half years later.

Two of the five cases of bronchopleural fistulas and two of the three deaths are found within the series of 17 cases in which oleoplombage was used.

One death occurred in the Lucite sphere group of patients. This patient was of Oriental extraction, and he was preoperatively classified a desperate risk. After lobectomy and prosthesis, he developed a fistula for which a thoracoplasty was performed; however, associated infection was overwhelming.

In the other four cases of bronchopleural fistulas, the prostheses were removed operatively and thoracoplasties were performed. All four patients achieved primary healing of fistulas and noninfectious elimination of the space.

Spread of disease followed surgery in three patients of the series. One patient, a Mexican teen-age girl, was in the desperate risk classification preoperatively. Sixteen months after a right upper lobectomy, she still is in the sanatorium, slowly improving, but still sputum positive. The remaining two patients who suffered spread of disease were recalcitrant to postoperative therapy. Neither accepted bed rest and one refused chemotherapy.

Infection of the prosthetic space, without bronchopleural fistula, occurred in the one patient in whom a Lucite sponge was used as the prosthetic material. Since the dominant growth of the infection was *Pseudomonas aeruginosa,* we suspected contamination of the space as a result of difficulties in sterilizing the prosthetic material, and we abandoned further use of sponge prosthesis.

Several causes account for the three deaths encountered in the series. The first death occurred in a male patient who was discharged from the sanatorium as a probable cure. Six months later he was found dead in his home. Death had taken place several days previously, and the cause has never been determined. The second death happened four days after resection and no autopsy was obtained. Cause of death was assumed to be a pulmonary embolus. The third death in the series was the Oriental patient mentioned in the discussion of bronchopleural fistulas.

All of the complications mentioned previously occurred in the first 48 patients in the series; whereas the last 62 patients were free of these difficulties. As will be seen, this improvement resulted, in all likelihood, from the change of the prosthetic material from oil to spheres, and from the discovery of a more adaptable method of using these spheres.

PROSTHETIC TECHNIQUE

Our technique for extrapleural prosthesis has evolved through several developmental stages. Our first patients in the series were given a temporary air space which later was filled with oil. While this method fulfilled a few of the criteria for good functional prosthesis, an airtight pocket could not always be obtained at the time the operation was performed since the parietal pleura was occasionally torn in the process of separating adhesions. This, and the need for periodic pressure checks—and, in several patients, the loss of the air space—were factors which combined to force our search for a more satisfactory prosthesis.

In one case in which an airtight pocket was unobtainable a temporary substitute was fashioned with a Brake bag. The result was very satisfactory in maintaining the pocket, but we had difficulty later in removing the bag, and we felt also that the hazard of infection was too great to warrant a continuation of this procedure.

Gale and his associates[3] have reported the use of Lucite sponge for extrapleural prosthesis; our experience with an infection following the use of an Avalon sponge prompted our change to the use of hollow Lucite spheres.

Spheres were used in 92 cases. In the first of this particular series, we tied the spheres together and secured the resulting cluster to Sibson's fascia.

Fig. 1.

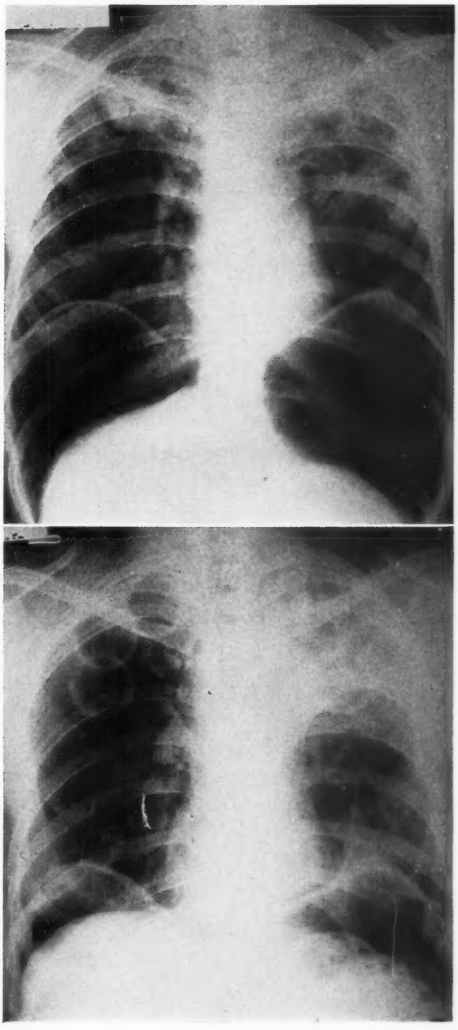

Fig. 2.

Fig. 1.—F. F., a 43-year-old woman with bilateral upper lobe cavitation who had a sputum conversion on chemotherapy but persistent chronic cavernous disease.

Fig. 2.—Same patient after bilateral upper lobectomy with extrapleural Lucite sphere prosthesis.

Fig. 3.

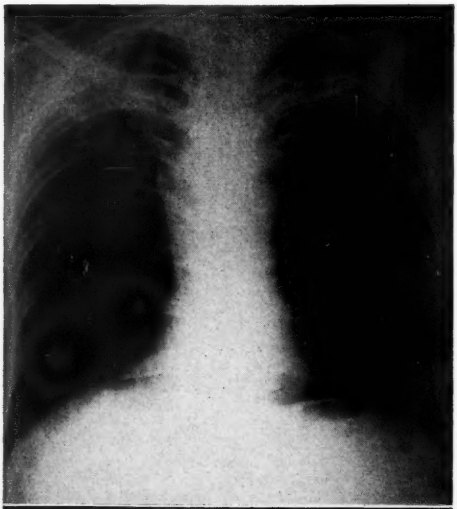

Fig. 4.

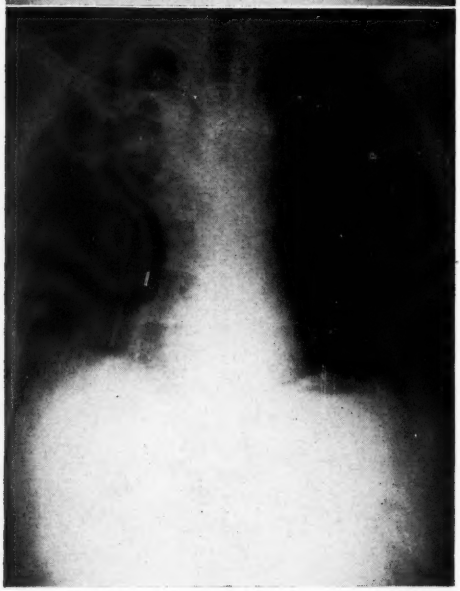

Fig. 3.—R. A., a 44-year-old man with bilateral apical tuberculosis, accentuated on the right side. Preoperative bronchospirometry studies revealed borderline pulmonary reserve due to bilateral lower lobe emphysema. The preoperative studies indicated that further distention of emphysemic areas would result in further diminution of borderline alveolar function.

Fig. 4.—Same patient following right upper lobectomy with replacement extrapleural prosthesis.

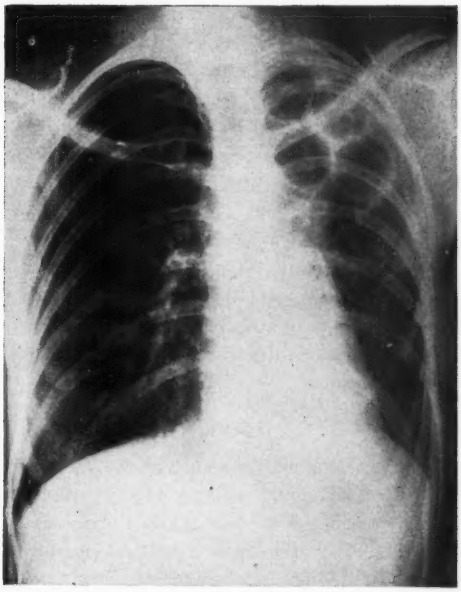

Fig. 5.—Postoperative film of extrapleural Lucite prosthesis following left upper lobectomy.

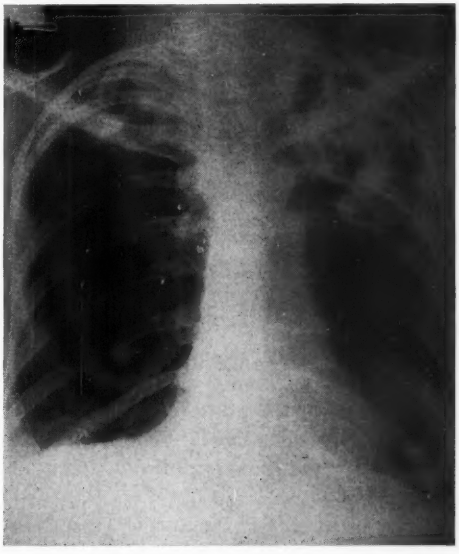

Fig. 6.—E. T., a 40-year-old woman who had an unsuccessful collapse attempted by an extrapleural Lucite pack. Her second surgery consisted of a *left* upper lobectomy under the Lucite pack, and her third surgery was a *right* upper lobectomy with an extrapleural prosthesis.

Several methods of grouping the spheres were tried. For instance, holes were drilled through their centers for ligature grouping. In every case of this kind, levels of fluid developed inside the spheres, a matter which not only caused confusion in x-ray follow-up procedures but which turned the spheres into potential foci of infection.

As a means of keeping the spheres together, small orthopedic screws were inserted in their walls and the ligatures attached to these. Solid balls of the Lucite with holes bored through them were also tried in our search for the best prosthetic method. These last two maneuvers were effective; but we later found it unnecessary to group the spheres at all.

In each of the final 85 patients in the series the spheres were emplaced loosely and were localized only by the reconstructed pleural diaphragm. This method of extrapleural prosthesis has proved to be the most adaptable and has resulted in fewer complications.

COMMENT

Postoperative complications which result from overdistention of the remaining lung tissue are reduced whenever collapse is instituted concurrently with the lobectomy. Pulmonary resection in this manner and replacement by a prosthesis is, of course, attended by the same complications either procedure entails when done separately. Immediate postoperative difficulties consist of operative shock and bronchial spread of the disease. Later complications may embody the various stages of infection, including bronchopleural fistula, development of empyema, and spread of disease by overdistention of quiescent lesions. However, in the 110 cases discussed, complications occurred in only 8 per cent, while the final 62 cases (56 per cent) were free of complications.

The ratio of complications to cases was approximately 1 to 15 in the sphere group as compared to 1 to 8 in the oleoplombage group.

Since, proportionally, the large series of cases in which Lucite spheres were used had about 50 per cent fewer patients with complications than had the small, earlier prosthetic group, it may be concluded that loosely emplaced Lucite spheres offer a far preferable prosthetic method.

SUMMARY

1. Extrapleural prosthesis was performed concomitantly with resection in a series of 110 cases. Prosthesis consisted of oleoplombage in 17 cases, of a Lucite sponge in one case, and of Lucite spheres in 92 cases.

2. The indications for preventive collapse following resection are given.

3. Concomitant lobectomy and tailoring pleuroplasty for extrapleural prosthesis offers surgeons and patient a number of advantages over the combination of lobectomy and thoracoplasty.

4. The technique is outlined for the surgical procedure, emphasis being given the problem of developing the extrapleural pocket.

5. Complications occurred in only 8 per cent of the cases. The complications were bronchopleural fistula, spread of the disease, and infection of the prosthetic space.

6. Three deaths occurred in the series. One was six months after discharge and was of unknown cause. One was presumably caused by a pulmonary embolus. One followed an overwhelming infection that accompanied a bronchopleural fistula.

7. Various types of extrapleural prosthesis were tried. Free Lucite spheres placed above a reconstructed pleural diaphragm were most satisfactory.

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SUGGESTED MODIFICATIONS IN THE APPLICATION OF THE SIGMAMOTOR PUMP TO THE TECHNIQUE OF CONTROLLED CROSS CIRCULATION

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FAMILIARIZATION experiments in dogs using the controlled cross-circulation technique of Lillihei and associates[1, 2] for the direct vision method of closure of certain congenital intracardiac defects in human beings have led to several valuable modifications in the application of the Sigmamotor Pump.

By means of the multifingered Sigmamotor Pump, which massages fluid by serially applied pressures on the outside of two pieces of tubing, equal rates of pulsatile blood flow may be established in two external circuits of small volume. In use, the circuits are connected (Fig. 1) by means of catheters so that oxygenated blood from a donor artery is pumped into the ascending aorta of the recipient, and the venous return, excluded from the right heart, is collected from the superior and inferior venae cavae of the recipient and pumped into the venous system of the donor. If the flow rates are equal, blood volumes in the donor and recipient remain unchanged, and the donor, through hyperventilation with 100 per cent oxygen, is capable of aerating both his own circulation and that supplied to the recipient.

Some difficulties inherent in this procedure have been met by the following modifications:

1. An adjustable collar for fine calibration of flow balance.
2. A reservoir applied to each system as a hydraulic cushion in the event of restriction of either inflow catheter.
3. A means of rapid replacement of blood loss during the operative procedure.
4. Plastic ridges applied to the caval catheter to facilitate placement through the heart.

METHOD

These modifications are illustrated in Figs. 1 and 2. A short piece of Tygon tubing is cut so that when securely adapted over glass connecting tubes, with the closed adjusting collar against the input face, a slight amount of tension is maintained on the Tygon when mounted in the pump. An inverted 100 ml. pipette is connected in each system to the upright stem of the glass crossarm with a short piece of Tygon, and the tip of the pipette is closed with a rubber tube and clamp. The side arm is connected to a small diameter

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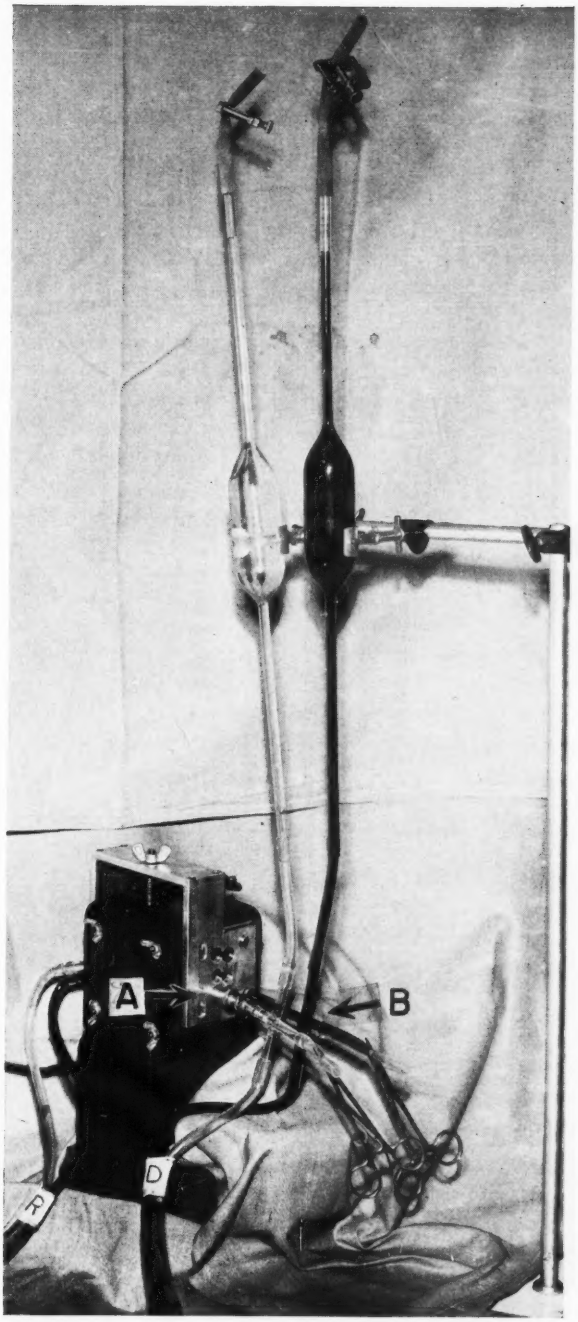

Fig. 1.—Pumping head from the input side, showing the adjusting collar, *A*, and the cross-arm connector, *B*, as assembled for use. *D* is the donor circuit; *R* is the recipient circuit. Flow is from right to left; venous circuit is filled with dye for clarity.

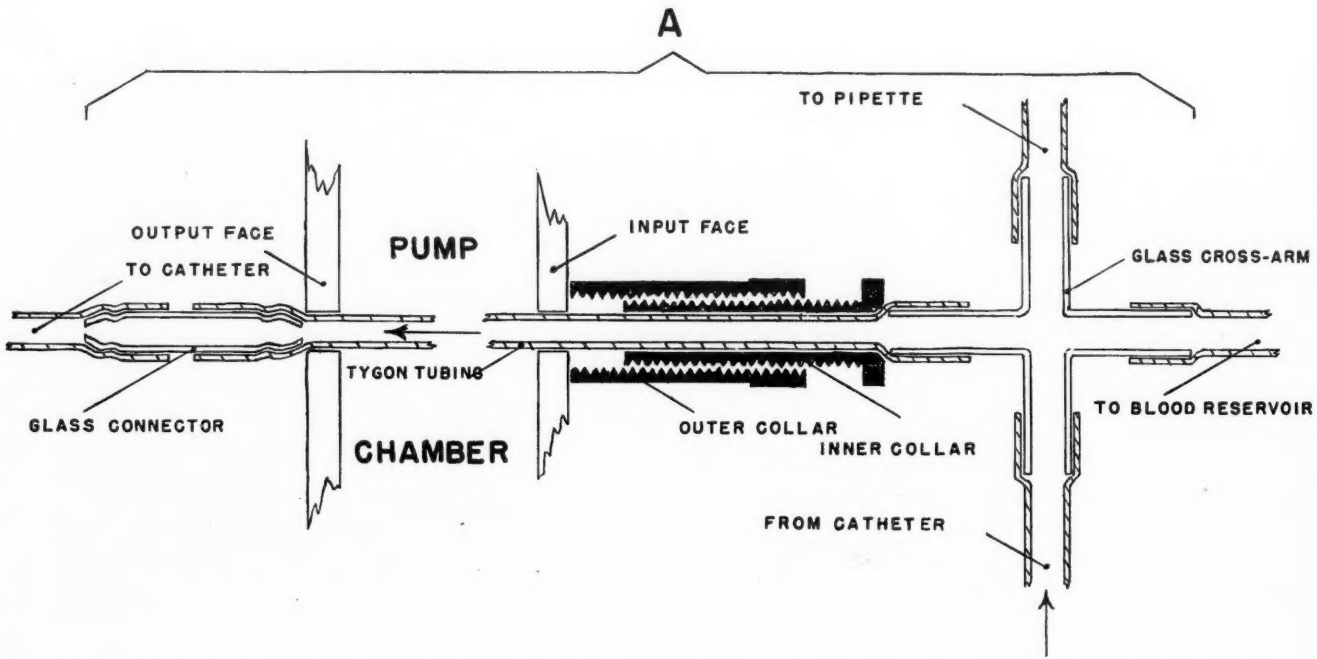

Fig. 2.—Detail of adjusting collar and connecting tubes. Flow indicated by arrows. Dimensions determined by size of tubing used in pumping chamber.

Tygon tube which is clamped, ready for use with an infusion setup. The system is filled with saline by running the pump, a valved suction bulb being used to draw saline into the pipette. The system is freed from bubbles, and the fluid reservoir is partially degassed by repeated clamping of the intake catheter while the pump is operating.

DISCUSSION

Sensitive flow balance, within 1 c.c./5 min., may be made with an adjustable control collar on each circuit. By distracting the control collars, it is possible to decrease the internal diameter of the tubing passing through the pump, thereby obtaining a decrease in output volume per pulse. The glass connectors, fitting the tubing tightly, are held at the outlet face and at the end of the control collar to eliminate creep of the tubing through the pumping chamber.

The level of the saline in the pipettes is a sensitive indicator of flow dynamics, any restriction of intake resulting in a sharp lowering of the fluid level in the narrow upper stem. Since such restriction of intake will often suck air into the circuit at the point of adaptation of tubing and catheter or, at least, will cause extensive degassing of the blood, the presence of the hydraulic cushion is a source of fluid supply until the catheterized vessel can refill. A standard Abbott disposable Blood Recipient Set is used as an elective supplementary blood supply, either to augment blood volume in the event that an intake catheter becomes occluded because of insufficient supply or to compensate for coronary spillage while the heart is open. The needle adapter is connected directly to the side arm, and blood is drawn into the circuit whenever the side-arm clamp is released.

Bubbles in the circuit may be persuaded to find their way into the pipettes by proper manipulation of tubing and catheters, eliminating disconnections after the catheters are inserted.

The unit *A* (Fig. 2) may be entirely removed from the pump, cold sterilized and replaced in the same side without upsetting flow balance settings. Other elements of the circuit, if disconnected to avoid thermoplastic loosening of the Tygon junctions, may be steam sterilized. The use of Tygon through the pump requires release of the pressure plates when standing idle to minimize compression set of the plastic and consequent loss of calibration.

In the event that an inlet should lie within the atrium, fatal air emboli are drawn into the circuit when the heart is opened. Narrow rings are cut from catheter tubing and afixed to the caval catheter at each extreme of the solid portion which is to pass through the atrium. The rings are easily palpable through the vein wall during placement and, when the caval tapes are tightened centripetally, serve to maintain position of the perforated areas.

Through the incorporation of the above features, accurate preoperative calibration and a sensitive indicator of flow-dynamics during pump operation have been obtained. Yet there is no constant monitoring of quantitative changes in blood flow rates that may take place during surgery. Such changes are brought about especially through variations in the arterial blood

pressure head in the donor individual and through obstruction of the venae caval catheter in the recipient individual. The latter complication is frequently initiated by excessive arterial blood loss through an incompetent aortic valve and the ventricular septal defect in the open heart. The venous return is thereby diminished and the venae cavae are sucked into the intake openings of the catheter. This chain of events can be controlled to a great extent by intermittent occlusion of the ascending aorta while the heart is open, thereby preventing regurgitation of blood through the aortic valve. In addition, smaller intake holes in the collecting catheter, or the incorporation of a blood reservoir between the recipient individual and the pump, will reduce the hazard of catheter obstruction in the recipient individual. We feel, however, that it would be beneficial to have an efficient, but not too complicated flow-meter incorporated in each circuit so that the exact rates of blood flow in both directions would be known at any given instant.

SUMMARY

Modifications are suggested for the use of the Sigmamotor Pump in cross-circulation procedures. They present the following improvements and safeguards:

1. Accurate and permanent adjustment of flow balance by means of a simple expansion collar.
2. Diminution of the major hazard of air emboli from the extracorporeal circuit by furnishing a fluid buffer system.
3. A readily observable indicator of flow dynamics.
4. Addition of a blood reservoir for rapid replacement of blood volume as necessary.
5. A method aiding the accurate and secure placement of the catheter in the superior and inferior venae cavae of the recipient.

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A NEW FINGERNAIL COMMISSUROTOMY KNIFE FOR MITRAL VALVE SURGERY

By Alvin A. Bakst, M.D.,* Brooklyn, N. Y., and Austin R. Baer,** New York, N. Y.

WE WISH to report the development of a new fingernail mitral commissurotomy knife, which greatly simplifies the technique of mitral commissurotomy. Concomitantly, with this instrument, the safety of the procedure is enhanced, inasmuch as the inadvertent production of a complicating mitral regurgitation is obviated.

The pathology of the stenotic mitral valve has been described at length,[1, 2] and is not a topic for discussion in this paper. It is sufficient to say that the end result is a narrowed, slitlike, rigid valve orifice, with thickened valve leaflets, and with agglutination, and thickening of the chordae tendineae. The chordae are aligned longitudinally in two rows, one to the edge of each agglutinated valve leaflet. The anterior commissure of the stenotic mitral valve tends to form a fine, curved, grooved line, extending from the anterior portion of the stenotic orifice to the myocardial wall. This fine line is the landmark which the surgeon uses to guide safely the splitting of the stenotic valve between the chordae. If the valve should be split outside of this line, a serious complicating mitral regurgitation would result. Splitting the valve outside the line, in the direction of the mural leaflet, is not attended by nearly as significant a regurgitation as would be produced by a similar split in the aortic leaflet. Also, the instrumental cutting, or the digital tearing of a chorda tendinea is attended by a flaccid valve leaflet and a severe regurgitation.

Not every stenotic mitral valve requires instrumentation during the performance of mitral commissurotomy. An instrument is required in about 50 per cent of the cases, however, if the commissure is to be completely opened to the heart wall. A few valves split easily by mere insertion of a finger through the orifice. Calcified valves usually split easily initially, after the finger has been inserted. They do not always open easily to the heart wall, however, and may require additional instrumentation to obtain an adequate two-finger opening. The valves which invariably require cutting are those which theoretically should give the best results, and yet are fraught with the greatest danger of a complicating regurgitation. These are the slightly thickened, noncalcified valves, which are freely mobile save for the presence of a thick, heavy, fibrous annulus around the stenosed orifice. These valves do not split readily by digital commissurotomy and invariably require initial instrumentation. After the initial cut in the annulus, they may split easily on application of

This instrument was developed during the tenure (A. A. B.) of a Thoracic Surgical Residency with the Bailey Thoracic Clinic, and Hahnemann Medical College and Hospital, Philadelphia, Pa.

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pressure with the tip of the finger, or further instrumentation may be required to gain an adequate two-finger opening. These are the valve leaflets which are almost normal and, theoretically, should be attended by the best long-range functional results. Yet, a slight deviation in the cut from the true commissural line may result in a regurgitation which is at least as threatening as the original stenosis if not more so.

At all times it must be remembered that it is of utmost importance to perform the commissurotomy without the production of a regurgitation or without significantly increasing any minor existing one. In the accomplishment of this, the integrity of the commissure must not be violated.

Several factors of importance must be considered in the designing of an instrument:

1. The instrument must facilitate extremely delicate cutting of the agglutinated valve leaflets. It must make possible meticulous commissurotomy, and permit small incisions so that following each cut a regurgitant jet may be felt for, by means of which an early, minimal regurgitation can be detected. It should not permit the performance of a gross split, which may produce a large regurgitation. The production of a significant regurgitation may very well prove to be fatal or may produce congestive failure in the postoperative period.

2. Frequently, commissurotomy must be performed in the presence of a thrombosed auricular appendage or an intra-atrial thrombus. Under this condition, gentleness in technique is of utmost importance in the prevention of manipulative embolization. It is important to design an instrument which can be worn upon the initial entrance of the finger into the atrium and does not necessitate repeated reinsertions of either the finger or other instruments into the heart. Obviously, each manipulation enhances the risk of embolization.

3. The instrument must be one which does not impair full tactile sensation by the delicate palpatory tip of the index finger. Simultaneously, it must facilitate the accurate cutting of the stenotic valve exactly along the commissural line.

4. It should be one which permits the index finger to palpate the valve leaflets and the commissure at the identical moment that it is performing the instrumental commissurotomy.

5. It must be an instrument which is carried on the index finger at the time of its initial entrance into the left atrium and may be used or not at the discretion of the surgeon. In the event that the knife is not needed, it must not in any way hinder digital action during the commissurotomy.

Several types of instruments have been previously devised for the performance of instrumental commissurotomy.[3-9] Some are introduced into the left atrium along the volar aspect of the index finger and prevent simultaneous palpation of the valve at the exact time of instrumentation, when it is needed most. Others are worn over the tip of the index finger. These require several

reinsertions of the finger into the heart and, by covering the tip of the finger, preclude the possibility of its adequate palpatory sensation during the cutting of the valve. An inaccurate cut will be attended by the usual complications of a poorly aligned commissurotomy, namely, regurgitation, congestive failure, and possible subsequent mortality.

After considerable experience in the palpation of stenotic mitral valves and in the performance of mitral commissurotomy, one of us (A. A. B.) noted that when the valve annulus was fibrotic or calcific and difficult to open, he always attempted to split the anterior commissure with the fingernail of the index finger. This experience provided the initial stimulus and realization of the necessity for the development of our present knife.

It was obvious that it was necessary to develop a steel fingernail knife; one which, in effect, replaced the free edge of the existing nail by a small steel blade. Concomitantly, it was essential to preserve the integrity of the palpatory tip and side of the finger, so that it was in no way impeded during the palpatory exploration of the mitral valve and the left atrial chamber.

The knife which we have developed is a fingernail commissurotomy knife. By use of a narrow, snug-fitting ring placed high around the distal phalanx, a steel fingernail is maintained in position over the existing fingernail, which, in turn, places a small crescent-shaped blade immediately beneath the free edge of the nail (Fig. 1). This blade is sharply edged, and projects beyond

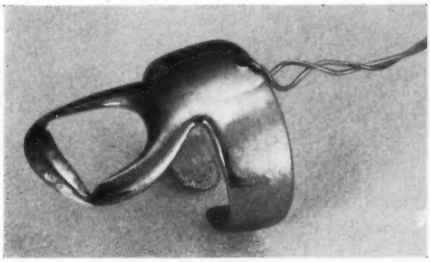

Fig. 1.—The ring portion of the fingernail mitral commissurotomy knife is attached to a steel fingernail, which is molded to the cuticle. The steel fingernail, in turn, places a small crescent-shaped blade beneath the fingernail. A small hole is made in the ring for the attachment of a length of steel wire, as an added safety factor in preventing the disengagement of the instrument while in the heart.

the free edge of the fingernail for a short distance, extending out only as far as the tip of the fleshy portion of the finger (Figs. 2 and 3). On slight pressure of the finger tip, the fleshy portion is forced back, thus exposing the fingernail blade. This then tends automatically to sheath the knife blade and permit it to be bared only when its use is desired. The ring portion is placed on the distal phalanx of the index finger immediately beyond the distal interphalangeal crease (Fig. 4). It is narrow, and slightly beveled, so that the knife cannot slide on digital flexion. This also permits the entire ball and side of the finger tip to be available for palpation. The fingernail portion is tailor-fitted over the existing fingernail, so that it is hidden in the recess formed by

the perionychium. This serves to conceal the entire knife within the contours of the existing nail. A small hole is made in the ring portion for the attachment of a length of steel wire, as an added safety factor in preventing its disengagement while in the heart.

The entire knife is made of stainless steel. There are no sharp edges or corners to cause snagging while in the heart, and simultaneously, there are no inaccessible surfaces to prevent its easy cleaning and sterilization. It is best sterilized in ordinary surgical scalpel sterilizing solution.

Fig. 2.

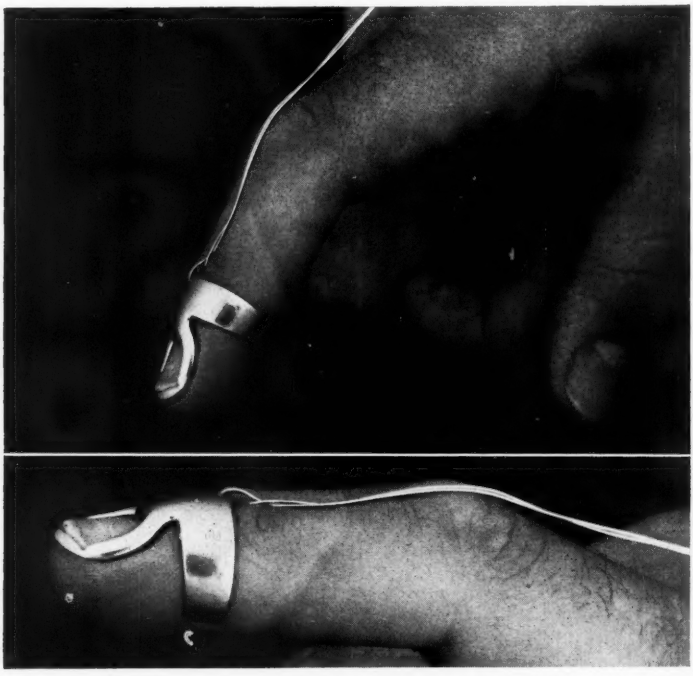

Fig. 3.

Fig. 2.—Oblique view of the right index finger, showing the fingernail knife in place on the distal phalanx. The crescent-shaped blade is beneath the edge of the fingernail and is maintained in position by it.

Fig. 3.—Close up of Fig. 2, showing the fingernail knife in place. The palpatory surfaces of the finger tip and the side of the finger are not impaired by the instrument.

The knife may be used on the bare finger, as some surgeons prefer to enter the heart, or it may be used under a rubber glove (Fig. 5). Should a glove be worn, after it is slipped on over the knife a small piece of rubber over the very tip of the index finger must be excised so that the knife blade itself may be properly bared while performing the commissurotomy.

Because of the tremendous variation in the size, shape, and contour of the distal phalanx and nail of the index finger of different individuals, it be-

came obvious that although it might be possible to establish standard sizes, in order to really fit perfectly and work well, the knife was best suited to be individually custom-made. Consequently, the manufacturer of the instrument has provided for individualization in the fitting and casting of the fingernail commissurotomy knife. This may be performed with only a minimal amount

Fig. 4.

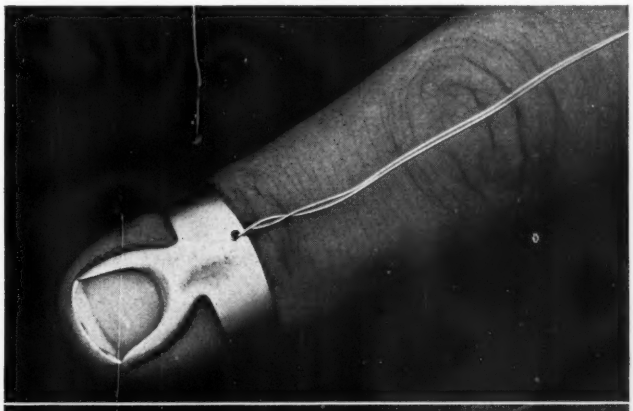

Fig. 5.

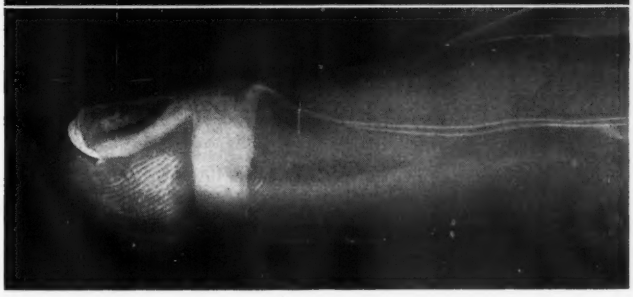

Fig. 4.—View of the dorsal aspect of the right index finger, showing the accurate fit of the fingernail portion of the knife over the existing nail, so that it is concealed within the contours of the recess formed by the cuticle. The blade projects beyond the fingernail and extends to the tip of the finger.

Fig. 5.—The ring is placed on the finger, after which the glove is slipped on. A small piece of rubber over the very tip of the index finger has been excised, so that the very edge of the knife blade may be bared while the commissurotomy is being performed.

of additional inconvenience. First, a mold of the individual surgeon's finger is obtained, from which a cast is made. The knife is then accurately molded to the shape, size, and contour of the individual fingernail and phalanx. In this fashion, the instrument becomes a custom-tailored, finely fitting, accurate, and precision-made fingernail knife. The perfect fit of the knife prevents the slightest motion of the blade during the performance of the mitral commissurotomy.

SUMMARY

1. A custom-made fingernail knife has been developed and described in detail.

2. This knife enhances the safety of the operative procedure of mitral commissurotomy in facilitating the accurate cutting of the stenotic valve exactly along the commissural line.

3. The precision with which the commissure can be cut obviates the production of any significant mitral regurgitation.

4. The instrument facilitates delicate cutting of the stenotic mitral valve.

5. The knife is worn on the index finger during its initial entrance into the heart, which obviates the reintroduction of the finger and other instruments. This is of importance in the prevention of embolization in the presence of auricular and atrial thrombi.

6. The instrument does not impair the palpatory ability of the finger tip. It may or may not be used, at the surgeon's discretion. If it is not used, it in no way hampers digital commissurotomy.

7. The knife is hidden in the recesses of the contour of the perionychium. This serves to sheath the blade of the knife so that its cutting action can be employed only at the surgeon's discretion.

8. Most important, it permits the valve leaflets and commissure to be palpated while the instrumental commissurotomy is being performed. This is the moment when simultaneous palpation is most crucial.

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USE OF THE RECORDING OXIMETER IN MANAGEMENT OF POSTOPERATIVE OXYGEN THERAPY

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CHICAGO, ILL.

PATIENTS who have had a surgical procedure involving the chest are found to be in a state of lowered arterial oxygen saturation in the immediate postoperative period. This can be explained on the basis of poor ventilatory exchange due to central depression from anesthetic agents, incisional chest pain and retained secretions, producing physiologic blood shunting through poorly or nonventilated areas of the lung. In young patients and in the absence of cardiorespiratory complications there is a spontaneous tendency to return to normal levels of arterial oxygen saturation shortly after surgery, when consciousness is complete. Mild sedation is then administered, and cough is encouraged. In older patients, the return to normal levels of arterial oxygen saturation is slower, cardiorespiratory complications appear more frequently, and functional adaptation to the new situation created by surgery takes longer.

Many authors have contributed a number of well-established facts to our knowledge and application of oxygen as a therapeutic agent. Cardiopulmonary physiologists like Cournand, Comroe, Christie, Wright, and many others have devoted numerous publications to such problems. Barach, in his book on oxygen therapy, made a very complete and careful exposition on the matter. A recent publication by Andrews[2] deals with this subject.

The deleterious effect of hypoxia has been repeatedly demonstrated and should be prevented or corrected by all available means in a patient who has just undergone major surgery and has still to overcome the injuries inflicted by surgery and disease. Since the conditions primarily responsible for this transitory hypoxia cannot be directly acted upon for its prevention, the routine practice of increasing the oxygen content of the gas mixture breathed by the patient during the postoperative period is effective in relieving this hypoxia and should be continued until the patient is able to maintain an adequate arterial oxygen saturation without aid.

The current practice of administering high levels of oxygen flow per minute via a nasal catheter to all patients after surgery on the thorax, although increasing the oxygen content of the blood, is not exempt from causing ill effects to the patient. Drying of mucous membranes with the production of tenacious secretions in the upper respiratory tract and the mechanical effects on the mucosa deter proper elimination of these secretions and predispose to atelectasis and pneumonia.

From the Department of Surgery of The University of Chicago.
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In the past, changes in pulse, respiratory rate, and clinical condition of the patient were used in common clinical problems as criteria to institute, stop, or regulate the amount of oxygen needed by the patient. It was then considered advisable to administer the patient oxygen flows between 5 and 10 L. per minute via a nasal catheter, and any flow under 5 L. per minute was thought to be of little value to the patient. These data, when properly interpreted, are of considerable help; but they do not have the same direct measuring quality as the arterial oxygen saturation level in determining the oxygen requirements of an individual case.

The use of the continuous-recording oximeter for the study of the clinical problems in this institution furnished us with an accurate method of judging the effectiveness and indications of the different techniques of oxygen therapy applied in the routine postoperative treatment of surgical chest cases and to correlate the validity of clinical criteria.

METHODS

Fifty patients on whom different thoracic surgical procedures were performed furnished the clinical material used in this study. Among the surgical procedures were pneumonectomies, lobectomies, segmental resections, thoracoplasties, aortic resection, mitral valvulotomies, and esophageal surgery. All these patients had reduced ventilatory efficiency, partially due to an operation on the chest wall.

Those with pulmonary resection had the additional factor of a reduction in lung capacity (Table I). A continuous-recording, Wood type, earpiece oximeter, built at The University of Chicago by Dr. Perkins and associates, was used for the arterial oxygen saturation determinations. The recording paper speed was set at 1 cm. per 2.5 minutes in order to make it suitable for several hours of continuous recording (Fig. 1).

TABLE I. USE OF THE RECORDING OXIMETER IN MANAGEMENT OF POSTOPERATIVE OXYGEN THERAPY

DISTRIBUTION OF OPERATIVE PROCEDURES	
Pneumonectomy	17
Lobectomy (partial or complete)	16
Exc. of emphysematous blebs and bullae	1
Chest wall operations	5
Miscellaneous intrathoracic (without excision of lung)	11
Total	50

Immediately after surgery the patient was transferred to the recovery room, where pulse rate, respiratory rate, arterial oxygen saturation, and clinical condition were carefully recorded on the oximeter record.

A base line for arterial oxygen saturation, pulse rate, and respiratory rate was then established by allowing the patient to breathe room air long enough to get a plateau for at least five minutes.

Oxygen, 100 per cent, was then administered by the following means: (1) a face mask connected to a McKesson machine with positive pressures of 10

mm. Hg applied; (2) B.L.B. face mask with an oxygen flow of 10 to 12 L. per minute; (3) via a nasal catheter as soon as the patient regained consciousness. Previous to this time the patient's tidal volume was insufficient to allow the use of a nasal catheter. Flows of 1, 2.5, 5, 7.5, and 10 L. per minute were then established, sufficient time being allowed between flow changes for the patient to reach sustained levels of saturation. The efficiency of the oxygen therapy was judged primarily on the basis of arterial oxygen saturation values; the patient was left on the lowest oxygen flow per minute necessary to maintain an adequate arterial oxygen saturation.

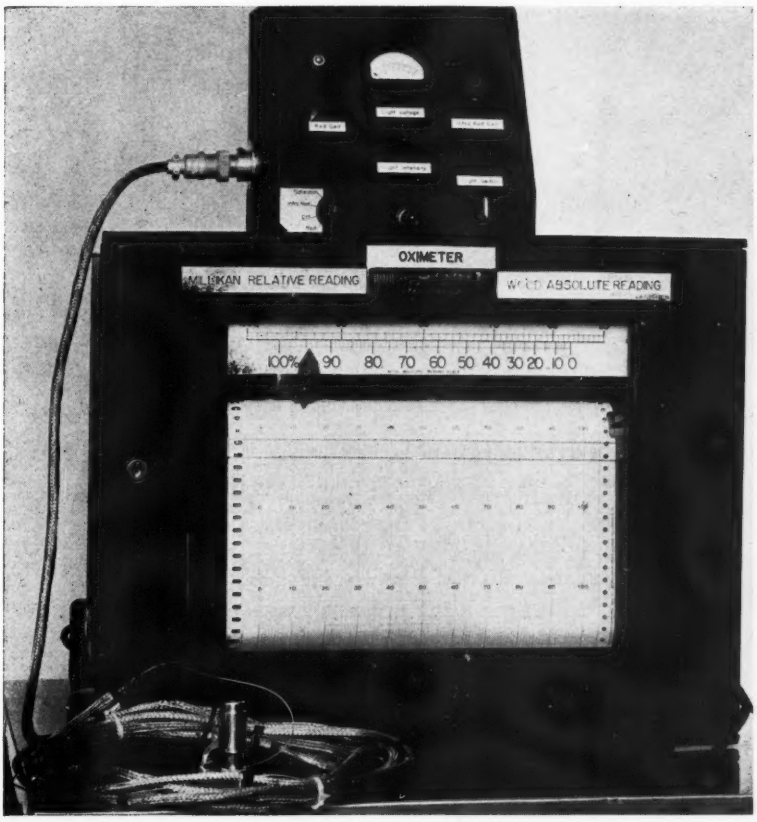


Fig. 1.—This is an actual photograph of the direct-reading, continuous-recording, Wood type oximeter. The earpiece in the lower left is applied to the patient. The control panel is seen up above. The easily visible large scale gives a direct reading in percentage of arterial oxygen saturation.

The patient was then followed in his room and checked as often as necessary to determine his oxygen requirements. Saturation determinations were made at least every twenty-four hours using the third method just listed.

RESULTS

In this series, 90 per cent of the patients showed a decrease in arterial oxygen saturation following surgery lasting from three hours to several weeks after the operation, depending primarily on the presence of cardiorespiratory complications. The average volume of all patients was 88 per cent of arterial oxygen saturation twenty-four hours after the surgical procedure, whereas normal figures of arterial oxygen saturation range from 96 to 98 per cent.

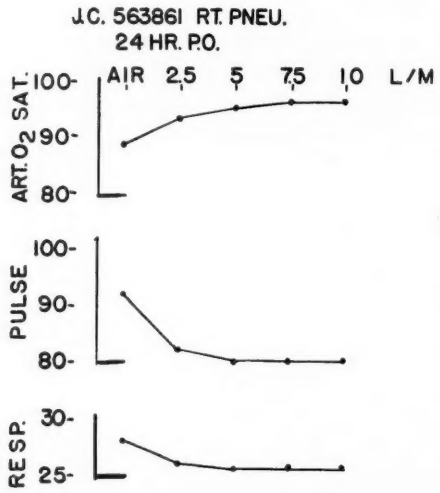
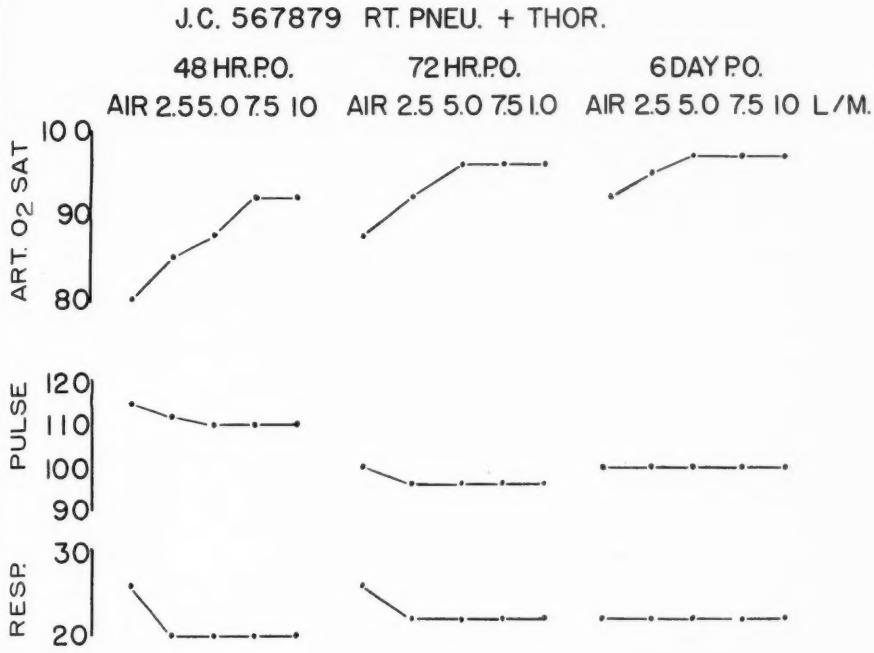


Fig. 2.—Response to oxygen via a nasal catheter in a 62-year-old patient twenty-four hours after a right pneumonectomy. Near to maximum rise in arterial oxygen saturation is obtained with only 2.5 L. per minute of oxygen flow. Notice the changes in pulse and respirations closely following the changes in arterial oxygen saturation.

This hypoxia responded quickly to oxygen therapy regardless of the way it was administered. When given 100 per cent oxygen with a McKesson positive-pressure machine, arterial oxygen saturation above normal values was reached within one or two minutes after starting. In twenty patients the average increase of arterial oxygen saturation was 10 per cent, a plateau maintained at 98 to 99 per cent levels. Completely similar results were seen when using B.L.B. masks with oxygen flows of 10 to 12 L. per minute.

The results in an average case are shown in Fig. 2. It will be noted that oxygen flows of 2.5 L. per minute when administered via a nasal catheter proved effective in raising the saturation to normal or close to normal levels in all patients without cardiorespiratory complications, whereas without this information, flows of 5 to 10 L. per minute are frequently used. The average increase in saturation obtained in all 50 patients, 24 hours after surgery, was 5 per cent, i.e., from 88 to 93 per cent. Five liters of oxygen flow per minute brought a rise in saturation of 7 per cent, from 88 to 95 per cent, or only 2 per cent higher than

that reached using 2.5 L. per minute. Higher oxygen flows of 7.5 and 10 L. per minute did not prove effective in raising saturation appreciably over the previous levels reached with 5 L. per minute in most patients.



Dr. adams 427/8/58

Fig. 3.—Response to oxygen therapy in a 62-year-old patient, 48 hours, 72 hours, and 6 days, respectively, after a right pneumonectomy and tailoring thoracoplasty. Improved arterial oxygen saturation corresponded with clinical improvement of the patient. Notice poor correlation of pulse and respiration with arterial oxygen saturation figures.

A decrease in pulse and respiratory rates occurred following the return of arterial oxygen saturation levels to normal. In 50 determinations made twenty-four hours after surgery the average decrease in pulse rate was found to be 10 per minute when raising arterial oxygen saturation to normal. Respiratory rate changes, although not as clear-cut as pulse rate, showed a decrease of an average of excursion per minute in similar conditions.

In a small group of patients, particularly after pneumonectomy and in those with cardiorespiratory complications such as retained bronchial secretions, atelectasis, and pulmonary edema, or in patients with marked emphysema, positive pressure oxygen, B.L.B. masks, or high flows of oxygen (7.5 to 10 L. per minute via nasal catheters) all proved equally effective in maintaining adequate arterial oxygen saturation through these transitory situations until they were corrected with proper treatment (Fig. 3).

In some patients the use of only 1 L. per minute oxygen flow via nasal catheter raised the arterial oxygen saturation 10 to 15 per cent, demonstrating how important even small amounts of oxygen are. This finding was only in patients with marked decrease in pulmonary reserve. This was observed preoperatively in patients with advanced pulmonary emphysema. It was seen following pneumonectomy in cases with severe complications such as atelectasis and bronchopleural fistula. Patients with pulmonary hypertension during the postoperative period also evidenced such response to small oxygen flows (Fig. 4).

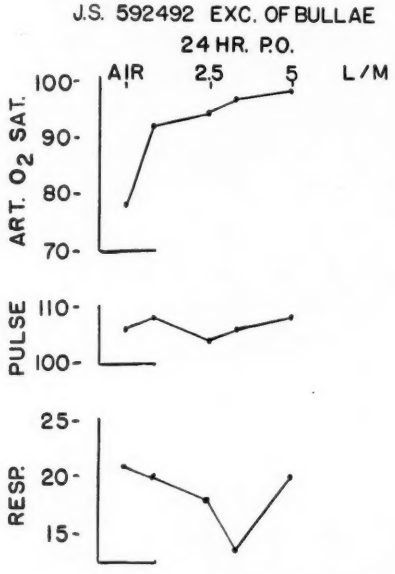


Fig. 4.—Response to oxygen therapy in a 59-year-old patient 24 hours after resection of left lower lobe for emphysematous bullae. Arterial oxygen saturation raised 14 per cent on 1 L. per minute of oxygen flow via a nasal catheter. Notice absolute lack of correlation in pulse, respirations, and arterial oxygen saturation values.

SUMMARY AND CONCLUSIONS

The use of oxygen therapy as routine procedure is indicated in all postoperative cases following major thoracic operations. In young patients without cardiorespiratory complications, these studies show that there is likely to be no need for oxygen following the day of surgery. In older patients and in the presence of cardiorespiratory complications, oxygen therapy may be necessary for a long period—until the patient is able to maintain an adequate arterial oxygen saturation while breathing room air.

Since adequate arterial oxygen saturation can be maintained on low oxygen flows of from 1.0 to 5.0 L. per minute, the use of larger amounts of oxygen is not only unnecessary and uncomfortable to the patient, but also dangerous to the extent that it thickens secretions which may lead to atelectasis.

The use of positive pressure and B.L.B. mask is indicated only when complications are present and for a few hours postoperatively. The amount of additional discomfort to the patient and the increase in nursing care and expense support this view.

Without an oximeter, one has to rely on the color of the patient, the pulse, and the respiratory rate. According to this study, a good rule to follow is to reduce the flow from 10 L. per minute to the point at which there is an increase in pulse rate and respiratory rate. This level is likely to be no more than 5 L. per minute.

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CLOSURE OF EXPERIMENTAL ATRIAL SEPTAL DEFECTS IN SHEEP WITH A SPECIAL ATRIAL RING CLAMP

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INTRODUCTION

A CLAMP has been developed which has proved effective in aiding surgical closure of atrial septal defects in sheep and which promises to prove applicable to human beings.[1]

The existing surgical techniques, which are amply summarized by Gross[2] and Björk and Crafoord,[3] have fallen into two groups, (a) the extracardiac approach and (b) the intracardiac approach.

Because of the ease and safety with which one is now able to palpate the interior of either atrium, it is advisable to use a combination of these two methods. To me, preliminary intracardiac palpation is an essential step in that it at once reveals the anatomical nature of the septal defect present including its site, size, and shape, and all the possible variations of these as fully described by Patten[4] in 1938. This important aspect having been determined, the surgical closure can then be accomplished.

THE EXPERIMENTAL WORK

On Nov. 6, 1952, experiments were started to find a simple method of closing atrial septal defects.

Sheep, especially lambs and hoggets, were chosen in preference to dogs as being essentially commercial animals with no sentimental value, readily available on the weekly stock market, inexpensive to keep, quiet, and easy to convalesce at Invermay Research Farm, eight miles in the country.

Anesthesia.—A half-hour before operation each animal received a subcutaneous injection of morphine ¼ grain and atropine 1/50 grain. Anesthesia was induced with veterinary Nembutal using a dose of 1 grain per 10 pounds of body weight, and injected through a No. 13 B-D needle into one external jugular vein. The needle was left in situ, and through it was threaded a fine polythene tube which was next connected to a glucose-saline drip. Muscular relaxation was obtained with intravenous Flaxedil, 1 c.c. (40 mg.). Thereafter, a No. 8 cuffed McGill endotracheal tube was inserted, and the animal connected to an open circuit Palmer pump while an assistant hand operated

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A 16 mm. color film of this procedure was shown before the Scientific Meeting of the Royal Australian College of Surgeons, Sydney, Aug. 20, 1953.

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the exhaust valve. The closed circuit of the Palmer pump was later used. With the closed circuit, the tidal air was adjusted to the weight of the animal, as seen in the chart (Fig. 1), which was finally constructed after trial had produced 25 sheep anesthesias with successful recovery.

Phase I.—In the first 10 operations, the heart was approached by a total splitting of the sternum. The aim was to assess the possibility of approximating the right and left auricular appendages through the normal interatrial septum, similar to the method of Swan.[5]

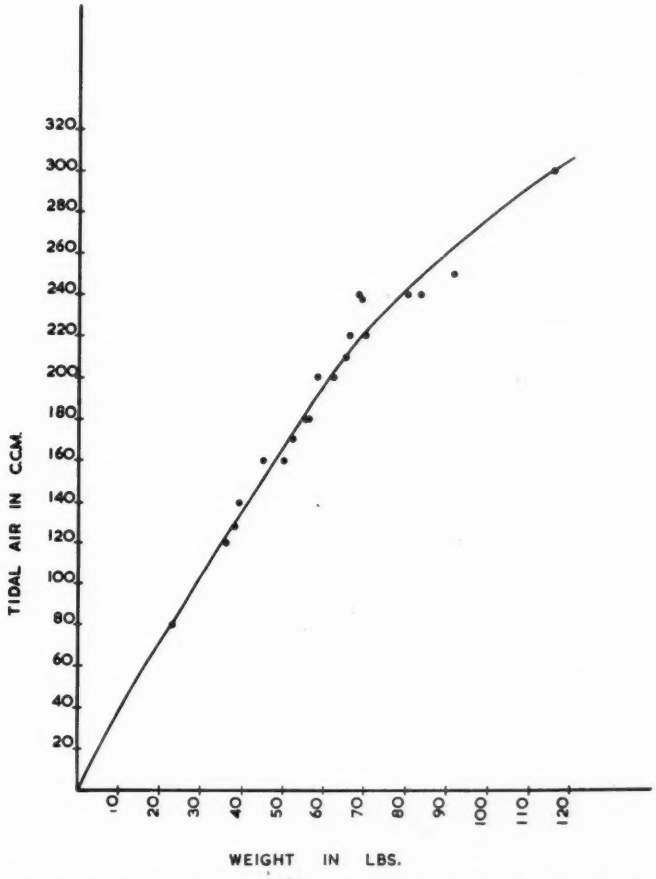


Fig. 1.—Chart showing relation between weight of sheep in pounds (avoirdupois) and tidal air as used on the closed circuit Palmer Pumps in 25 survival experiments.

Although at the first operation the auricular tips were held together by the left thumb and index finger, it was at once obvious that a clamp would prove a far safer and more efficient method of atrial approximation.

A box-jointed clamp, subsequently found to resemble the clamp that Dodrill[6] had made to create experimental defects, was fashioned with a central space to accommodate the heart and with two terminal rings of 18 mm. internal diameter. Unlike Dodrill's clamp, the rings were not complete circles; each had a gap $\frac{1}{16}$ inch wide in the circumference and placed opposite the attachment of the handle (Fig. 2).

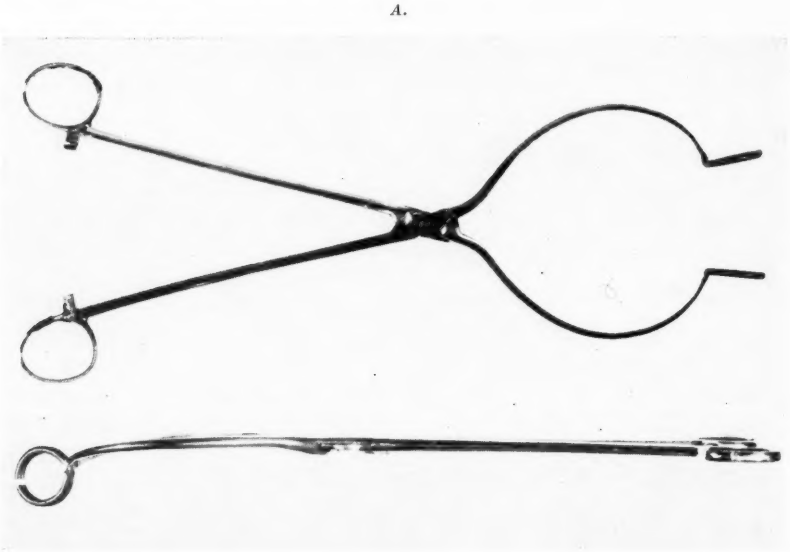


Fig. 2.—*A*, Atrial clamp from above; *B*, side view.

The box-joint enabled the blades to be removed separately if required, and the gap in the ring allowed safe removal of the clamp in those earlier experiments where one suture had been inadvertently placed over the ring. As only light pressure was needed to close the clamp against intraatrial pressure, accumulating experience showed that the gap in no way weakened the rings. Provided the clamp had not been placed in a position that obstructed the venous return to either right or left atrium, there was no cardiac embarrassment. The surprising feature was how well the heart tolerated the clamp, how regularly it continued to beat, and how easily it could be turned from side to side while the sutures were being inserted.

At first one, later two, double thread No. 4 silk mattress sutures were passed through the rings from left to right and back again, and tied. Thereafter, the pericardium was closed and a water-seal drain inserted. The sternum was not sutured, but the wound was approximated with interrupted silk sutures for the deep layers, and continuous catgut for skin. When the animal had recovered spontaneous respiration, the water-seal drain was removed. Penicillin, 200,000 units, was given twice daily for five days.

Results of Phase I: Seven of the ten animals survived this form of operation. Three died, from venous obstruction due to bunching of the auricles, from postoperative pleural effusion, and from atrial hemorrhage due to misplaced suture after removal of the clamp and at a time when the gaps in the rings had not been made.

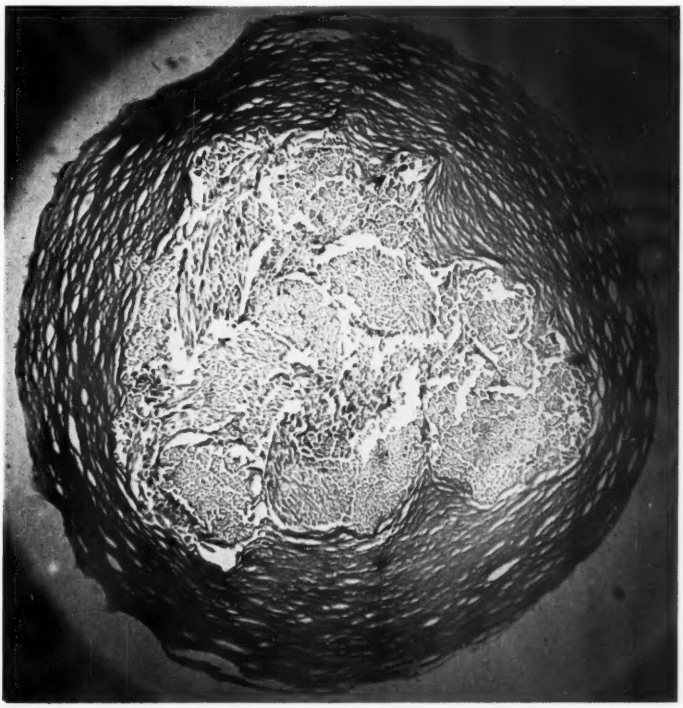


Fig. 3.—Photomicrograph. Silk suture surrounded by fibrous tissue (van Giesen) three months after being placed across lumen of left atrium. (Magnification ×20.)

Three months after operation the seven surviving animals were killed and the hearts examined. *Where one transfixing suture* alone had been inserted, the sutured part of the auricular tip had become an attenuated band across the atrial cavity. Microscopic examination showed that the silk fiber had become surrounded by concentric layers of fibroblasts (Fig. 3). *Where two transfixing sutures* alone had been inserted, there was a better coverage of the septum primum. (*Where three sutures* had been used, the animal had died at operation.)

It was therefore concluded that, having in mind the great anatomical variation in the site, size, and shape of atrial septal defects, this method of auricular approximation could not be recommended as a means of curing atrial septal defects.

Comment on Phase I: This series of experiments had nevertheless revealed: (1) that the atria are as tolerant of being clamped as are the auricular appendages; (2) that, anatomically, there was a considerable space to maneuver in the transverse sinus of the heart which lies in front of the atria and behind the origin of the aorta and pulmonary artery; and (3) that the interatrial septal line lies directly behind the origin of the arch of the aorta in front and to the right of the entrance of the right pulmonary vein behind.

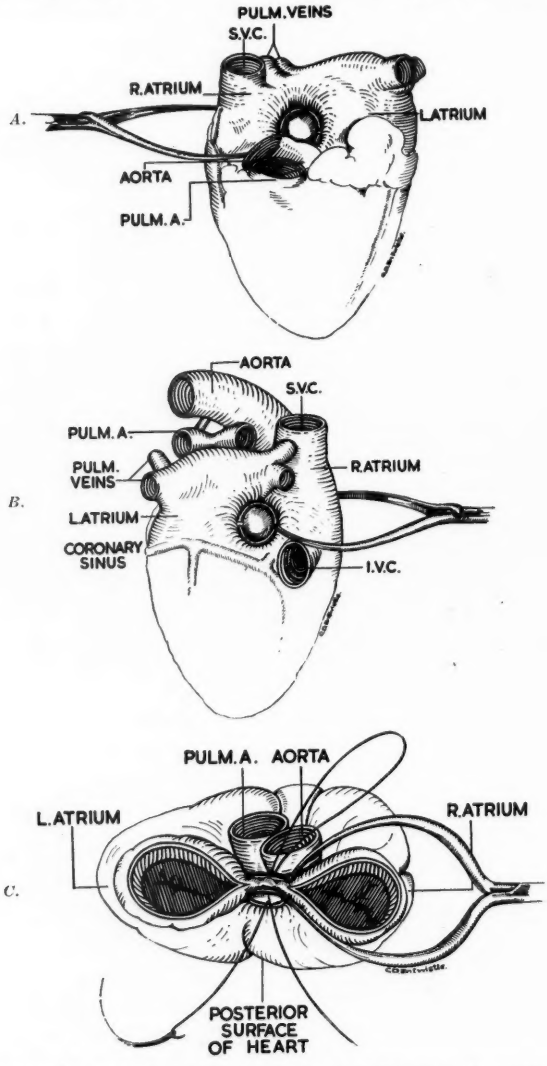


Fig. 4.—*A*, The anterior blade in position. *B*, The posterior blade in position. *C*, Plan from above, with one suture passed.

Phase II.—Realizing these facts, therefore, a second series of experiments was commenced on May 12, 1953. The heart was approached from the right side through the fourth rib bed. One blade of the clamp was placed in the transverse sinus, and the other lay behind the heart so as to lie *medial* to the line of the superior and inferior venae cavae below the right pulmonary veins and above the coronary sinus. The right pulmonary vein, which was a guide to the posterior attachment of the interatrial septum, was defined by dissection. Two or three mattress doubled No. 4 silk sutures were passed from behind forward, back again, and tied. (Fig. 4.)

Fig. 4, *D.*—View into transverse sinus of heart from the front showing two sutures in place. These were knotted from the front.

At first an artificial septal defect was not created as the aim of the experiments was to assess the tolerance of the heart to the clamp in this position, and to note any postoperative cardiac irregularity or embarrassment after tying the sutures. Again, cardiac tolerance of this anteroposterior clamping was remarkable.

Results of Phase II: Ten operations were performed. Seven animals recovered. Three died, one from anoxia due to a slipped endotracheal tube, and

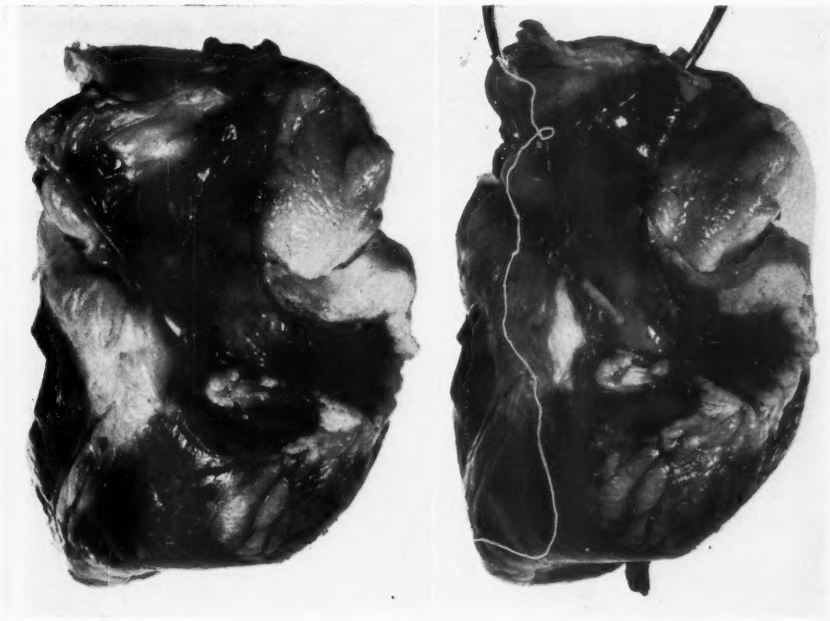
two from auricular hemorrhage following dissection of pericardial adhesions, the result of previous operations to create atrial septal defects. Examination of the seven hearts when the animals had been killed two months after operation showed that those sutures placed along the septal line had held, and in that area there had developed a broad sheet of fibrous tissue (Fig. 5).

Fig. 5.—View of interatrial wall from above, two months after sutures had been passed.

Phase III.—To test the method further and give finality to the experiments, it was decided to create atrial septal defects, close them immediately, and thereafter examine the heart, each operation being conducted as an acute experiment. One could thereby assess the degree of closure, undo the sutures, and then see the size of the defect thus closed. The occurrence of pericardial adhesions around all the operated hearts examined two months or more after operation, and the knowledge that experimental defects in time tend to close, supported this attitude.

In four other sheep, the right side of the heart was again exposed, the right auricular appendix clamped, incised, and the right index finger inserted into its lumen. With little pressure it was possible to rupture the septum primum, then remove the index finger, and close the atrial wall with two layers of continuous No. 4 silk sutures. Thereafter the atrial clamp was applied as above, and three mattress sutures were passed from behind forward and back

again. The sutures were tied from behind and the clamp was removed. The operation was then completed. Immediate autopsy showed that not only were these artificial foramina effectively closed, but also, when the sutures were untied, the foramina had measured on the average 1.5 cm. in diameter (Fig. 6).



A. *B.*

Fig. 6.—*A*, Artificially created atrial septal defect seen from right atrium. *B*, Defect held closed by clamp prior to suturing.

SUMMARY

A special ring atrial clamp* has been devised and shown to be effective in aiding extracardiac closure of experimentally created atrial septal defects.

One blade of the clamp was placed in the transverse sinus of the heart directly behind the base of the ascending aorta. The other lay behind the atrium and medial to the vena caval line above the coronary sinus and to the right of the right inferior pulmonary vein. The heart is remarkably tolerant of such clamping.

When mattress sutures are passed from behind forward and back again, and tied, closure of experimentally created defects has been shown to be effective.

*The clamp is obtainable from The Genito-urinary Co., Ltd., 28A Devonshire Street, London, W. 1.

It is surmised that this relatively simple method of closing atrial septal defects is applicable to man and that before closing them intracardiac palpation of the defect is advisable to assess the problem.

I wish to acknowledge great assistance from Dr. F. N. Fastier and the staff of the Department of Pharmacology, Dr. John Ritchie, head of the Department of Anaesthesia, Mr. Hall and staff of the animal department, and Miss Marshall of the Department of Photography—all of the University of Otago, and also from Mr. George Holmes, Director, Invermay Research Farm, North Taieri, Dunedin, and Mr. Moore of the engineering firm, Wilson and Wilson, Ltd., Dunedin.

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BRONCHOGRAPHY WITH OILY DIONOSIL

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SINCE its introduction in 1922,[1] Lipiodol has been generally accepted as the best available contrast medium for bronchography. However, the one serious objection to its use is its persistent visibility on chest roentgenograms made long after instillation, in many instances obscuring observations of the natural course of the pulmonary disease.

Chiefly for this reason, the search for a better contrast substance has led in the direction of rapidly absorbing radiopaque media. In recent years various rapidly clearing water-soluble media have been developed. These have consisted of Diodrast or related organic substances, in hypertonic aqueous solution made more viscid by the addition of a cellulose derivative (e.g., methylcellulose). Although these media clear rapidly from the lungs, they have introduced a new objectionable feature, that of bronchial irritation. To control the cough resulting from this irritation, more thorough and time-consuming anesthesia is required, and even then many unsatisfactory bronchograms result.[2, 3] The water-soluble media, therefore, have not received widespread acceptance, particularly in this country.

Recently a new type of contrast substance for bronchography, Dionosil, was developed in England.[4, 5] It differs from other media in that it is a *suspension* rather than a solution or an iodized oil. Early reports[6, 13, 16] indicate that it clears rapidly from the lungs, does not cause significant bronchial irritation, and results in bronchograms of excellent quality.

Dionosil contains propyliod-one, which is the n-propyl ester of 3.5 di-iodo-4-pyridone-N acetic acid. It is closely related chemically to Diodrast, which is the diethanolamine salt of the same acid. It is of low solubility in water and in peanut oil, and is manufactured as a 50 per cent weight/volume suspension in either an oily or aqueous vehicle. The oily form is a simple suspension of the ester in peanut oil. The aqueous form contains carboxy-methylcellulose as a suspending agent, sodium citrate as a buffer, sodium chloride for isotonicity, and a small amount of a wetting agent. Both forms contain about 30 per cent iodine. They are slightly less viscid than Lipiodol.

Since our experience is limited to oily Dionosil, the following remarks will relate only to this substance.

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Recent reports by Holden and Crone[6] and Cummins and Silver[7] describe the bronchographic experience with oily Dionosil in a total of 128 cases. They presented considerable evidence that oily Dionosil is a safe contrast substance for bronchography. No significant complication was encountered among these cases. There was no instance of iodism, either in the case material or after experimental ingestion by animals and human beings. Bronchoscopy following Dionosil bronchography showed no irritative effects on the trachea or bronchi, although one instance of mild clinical tracheobronchitis was mentioned. Coughing during bronchography was no more of a problem than with Lipiodol. Ten of the 128 patients were operated on soon after bronchography, and on pathologic examination of the specimens, no inflammatory reaction attributable to the Dionosil could be found. The postoperative course among these 10 patients was uneventful in all but one. This patient developed right middle lobe collapse which subsequently disappeared. The relation of the collapse to the contrast medium could not be ascertained.

MATERIAL AND TECHNIQUE

The present study is based on a review of the first 30 bronchograms performed with oily Dionosil* at the Cincinnati General, Daniel Drake Memorial, and Jewish Hospitals. These were compared as to technical quality, clearance time of the contrast medium, and patient reaction, with an equal number of unselected Lipiodol bronchograms.

The bronchographic technique in the two series was uniform. Patients were premedicated with Demerol, Nembutal, and atropine according to weight. When considerable bronchial secretion was present, postural drainage or bronchoscopic aspiration was carried out beforehand. Local anesthesia was performed by painting or spraying the pharynx with Pontocaine, and injecting 2 to 5 c.c. of 10 per cent cocaine into the trachea through a cannula. General ether anesthesia was used in children under 10 years of age.

When satisfactory anesthesia was obtained, a tracheal catheter was inserted to the region of the carina. The medium was injected at room temperature, the Dionosil requiring thorough shaking before use. In the average adult approximately 15 c.c. of contrast medium was instilled into each lung. Proportionately smaller amounts were used in children. In patients with poor respiratory reserve and in those in whom filling of only one lung was indicated, unilateral bronchography was performed. In all others complete mapping of both lungs was attempted at one sitting. During the injection the patients were postured in the usual manner, and the adequacy of filling was checked fluoroscopically. Usually several spot films were taken at this time. When filling of one lung was complete, recumbent anteroposterior and lateral Bucky films of the chest were obtained. The opposite lung was then filled and examined in a similar manner, but right and left posterior oblique views were substituted for the lateral. At the completion of the procedure, postural drainage was instituted.

*Supplied through the courtesy of Picker X-Ray Corporation, White Plains, N. Y.

RESULTS

In each series the 30 bronchograms were performed on 28 patients. The Dionosil cases ranged in age from 7 months to 74 years, with an average age of 39 years. The Lipiodol group ranged from 5 months to 72 years, and averaged 42 years. As seen in Table I, which lists the final roentgen diagnoses, the cases in the two series were similar.

TABLE I. FINAL ROENTGEN DIAGNOSIS

	DIONOSIL	LIPIODOL
Normal	9	5
Bronchiectasis	8	11
Slowly resolving pneumonia	3	1
Neoplasm	2	1
Congenital anomalies*	2	3
Bullous emphysema	0	1
Pleural disease	1	0
Unsatisfactory bronchogram	5	8
	30	30

*Anomalies include lobar agenesis, sequestration of lung, and anomalous bronchi.

TABLE II. ADEQUACY OF BRONCHOGRAPHIC FILLING

	DIONOSIL	LIPIODOL
Excellent	16	13
Good	9	9
Poor	5	8
	30	30

In Table II comparison is made between the two media as to the adequacy of bronchial visualization. The tabulation depended on whether the purpose of the bronchogram was to fill pre-selected segments (selective bronchography) or to fill one or both lungs completely (lung mapping). Filling was considered excellent in selective bronchography if the diseased bronchi were clearly depicted, and in lung mapping if all the segmental bronchi were shown (Figs. 1 and 2). It was rated good in selective bronchography if filling was incomplete but adequate for diagnostic purposes, and in lung mapping if one or two segmental bronchi did not fill (Fig. 3). Bronchograms were rated poor in selective bronchography if the diseased area was not visualized adequately for diagnostic purposes, and in lung mapping if more than two segmental bronchi failed to visualize (Fig. 4).

The slight difference in the extent of filling with the two media, noted in Table II, is not considered significant in view of the relatively small number of cases involved. Three patients had both Dionosil and Lipiodol bronchography. In one case the bronchial filling was excellent with both media (Fig. 5). Another case was rated excellent with Dionosil and poor with Lipiodol. The third showed good filling with Dionosil and excellent filling with Lipiodol.

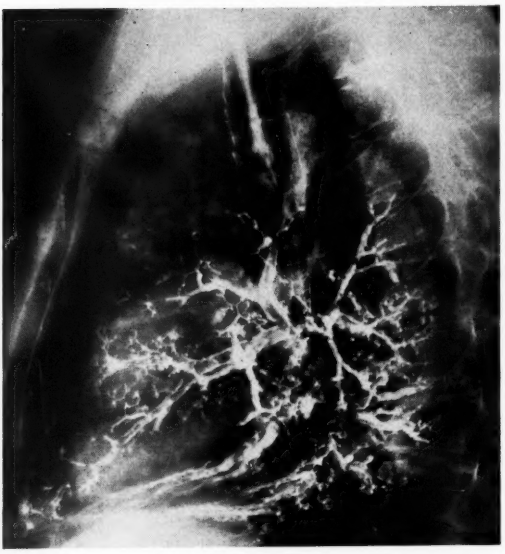

Fig. 1.—Lateral bronchogram of right lung (selective bronchography). Collapse of middle lobe and anterior and medial segments of lower lobe in slowly resolving pneumonia. Collapsed segments are well filled with Dionosil.

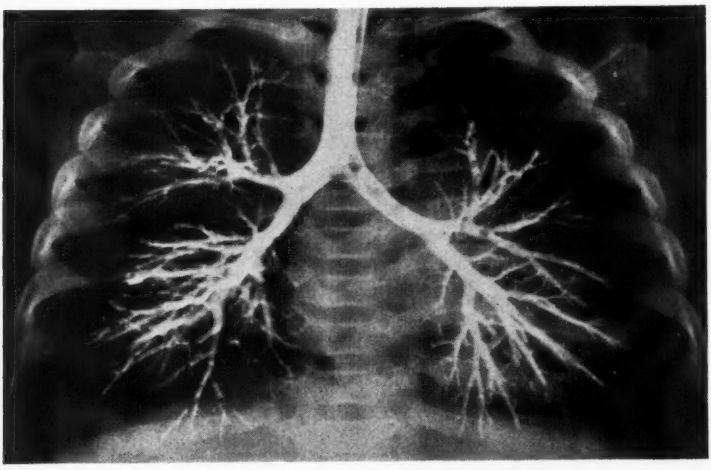

Fig. 2.—Normal Dionosil bronchogram in a child (lung mapping). All segmental bronchi were visualized.

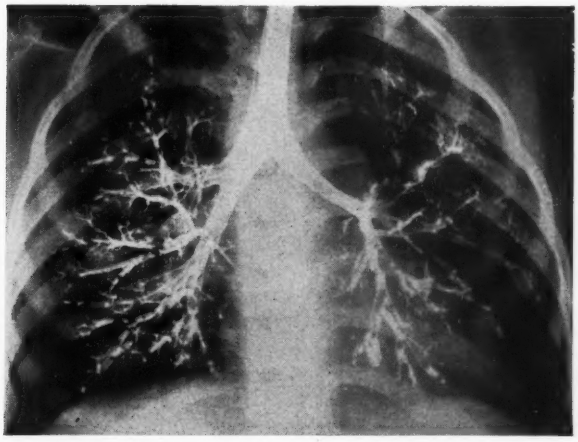

Fig. 3.—Dionosil lung mapping in bronchiectasis. The anteromedial and lateral basal segments on the left are incompletely filled.

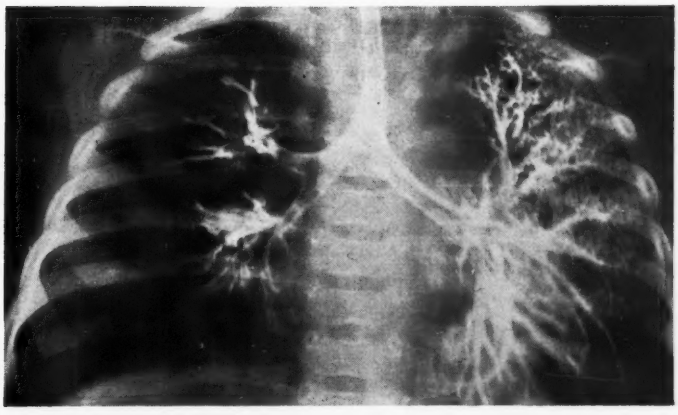

Fig. 4.—Unsatisfactory Dionosil lung mapping in a child. Flooding of left lung, inadequate filling of right lung.

Fig. 5.—Bronchiectasis right upper lobe. *A*, Dionosil. *B*, Lipiodol.

Holden and Crone[6] stated that alveolar filling did not occur with oily Dionosil. We have observed alveolar flooding with both media, although the Lipiodol did show a greater tendency to do so. There were 18 instances of flooding with Lipiodol compared to 7 with Dionosil (Fig. 4).

The relative ability of the two contrast media to coat the bronchial wall was compared. It was found that Dionosil more commonly produced a double contrast effect (Fig. 8, *B*). However, it was also noted that mucosal coating occurred more frequently when smaller amounts of either contrast substance were present in a bronchus, and this was especially true on films made near the end of the examination. A fairly widespread double contrast effect was noted in 15 Dionosil but in only 2 Lipiodol bronchograms. We do not, however, consider bronchial coating an important advantage.

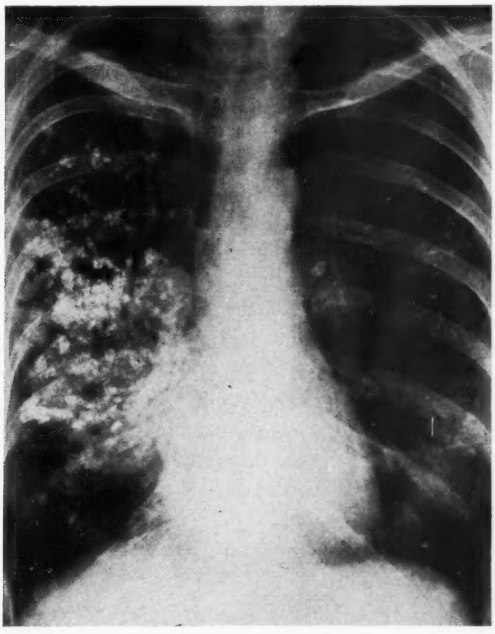

Fig. 6.—Comparison of clearance rates of Lipiodol and Dionosil. Lipiodol bronchogram on right, 5 days before, Dionosil bronchogram on left, 3 days before this film. The small opaque residue on the left is also Lipiodol. There is no Dionosil residue.

No untoward reaction which might be attributed to either contrast medium was encountered as an immediate or late complication. Dionosil was no more irritating than Lipiodol as far as could be determined from clinical manifestations. Cough was approximately the same with the two media; symptoms of bronchospasm were lacking; and a brief mild febrile response to the procedure occurred occasionally in each series.

The most important advantage of Dionosil over Lipiodol is the rapidity with which it disappears from the chest roentgenogram. Films were made approximately 24 hours after Dionosil bronchography in 29 instances, and after 48 hours or more in 8. The average amount of clearing of Dionosil in 24 hours was about 90 per cent. Complete disappearance occurred in 48 to 72 hours (Fig. 6). The slowest clearance rate encountered was 70 per cent in 24 hours.

In 18 Lipiodol cases, follow-up films were available varying from 1 day to 19 months after bronchography. The Lipiodol often remained in the lungs for weeks and even months. Retention was particularly striking in amount and duration in areas of emphysema and in segments where flooding had taken place (Fig. 6). The persistent shadow of the iodized oil often masked a parenchymal lesion, making serial film comparison difficult or impossible. It was particularly troublesome in the interpretation of postoperative roentgenograms and repeat bronchograms.

In seven Dionosil cases material for histologic study was available 1, 5, 5, 6, 7, 8, and 51 days, respectively, after bronchography. In addition to routine paraffin sections, fat stains were prepared in six cases. In three of these (two with carcinoma and one with bronchiectasis) chronic inflammatory changes were present. Intracellular fat droplets were visible, but it was impossible to determine whether this fat indicated endogenous lipoid pneumonia, a condition found in such cases, or represented phagocytized peanut oil. In two of the three (1 and 51 days, respectively, after bronchography) free oil, believed to represent residual contrast medium, was seen in the alveoli and bronchi. The remaining three specimens, obtained 5, 7, and 8 days, respectively, after bronchography, revealed free fat droplets in the bronchi and alveoli with no surrounding inflammatory reaction. There was no intracellular oil.

Although our pathologic material is limited, it appears that oily Dionosil causes no significant inflammatory reaction in the lungs. Cummins and Silver[7] stated that there was less oil in the lungs after Dionosil than after Lipiodol bronchography, and attributed this to the fact that Dionosil was less viscid and, therefore, more readily expectorated.

DISCUSSION

Oily Dionosil compares favorably with other contrast media used for bronchography. Like Lipiodol, it is much less irritating to the tracheobronchial tree than the water-soluble media, judging from the reports on the latter in the literature. Good anesthesia, therefore, is readily obtained, and cough presents no serious problem.

There is no significant difference between Dionosil and Lipiodol in contrast, density, or detail as seen on the roentgenogram (Figs. 5, 7, and 8), and both are superior in these qualities to the water-soluble media. However, Dionosil and the water-soluble media are slightly more difficult to see fluoroscopically than Lipiodol.

Fig. 7.—Carcinoma of right upper lobe. Oblique Dionosil bronchogram reveals deformity and obstruction of apical and anterior segmental bronchi.

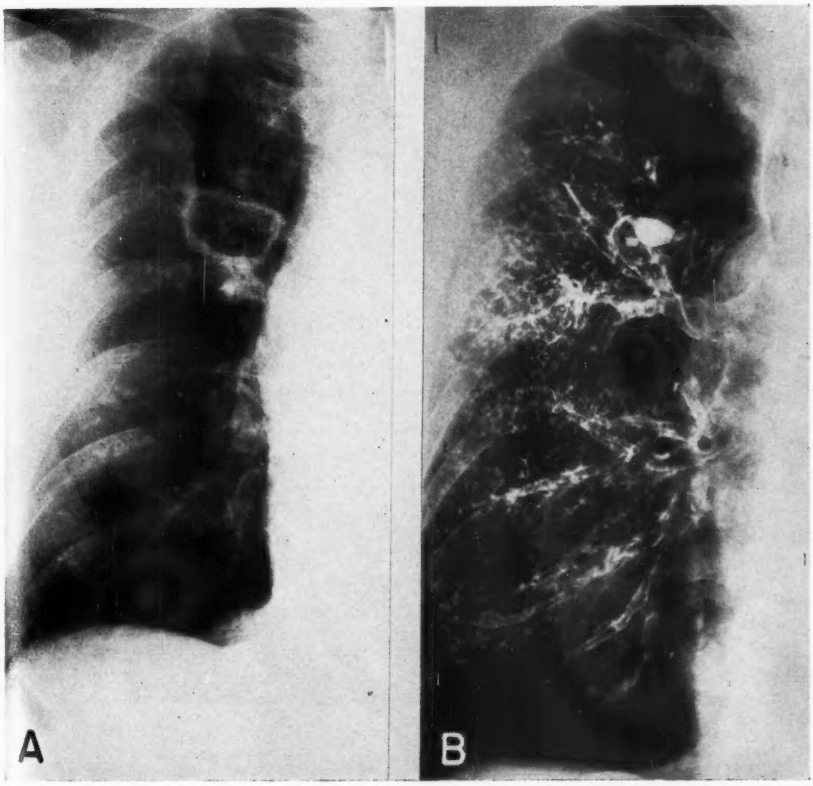

Fig. 8.—Bronchiectatic cavity right upper lobe. *A*, Chest film reveals small cavity in right upper lobe. *B*, Dionosil bronchogram shows filled cavity and its bronchial connection.

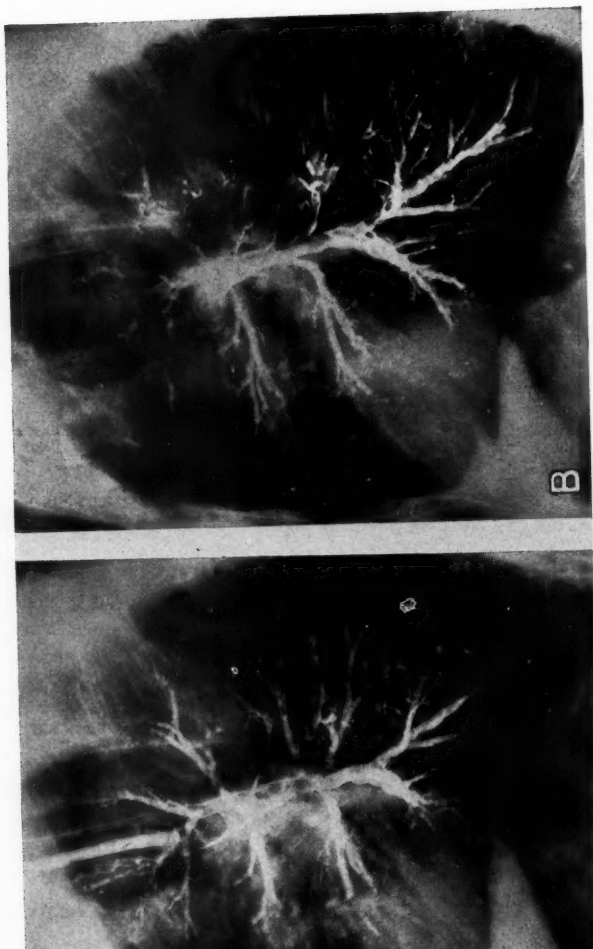

Fig. 9.—Lateral Dionosil bronchogram. *A*, Incomplete visualization of peripheral bronchi. *B*, Delayed film one hour later, showing improved peripheral filling.

Dionosil presents the major advantage over Lipiodol of rapid disappearance from the roentgenogram. It clears somewhat more slowly than the water-soluble media. This is also an advantage since it is not necessary, as it is with water-soluble media, to hurry the examination in order to avoid a blurring and smudging effect which obscures the detailed delineation of the bronchi. However, inordinate delay after Dionosil instillation may also cause this effect. It only occurs when repeat or delayed films become necessary for technical reasons. Nevertheless, we obtained an excellent delayed bronchogram, without smudging, one hour after Dionosil instillation in one of two attempts (Fig. 9). The rapid clearing of Dionosil, virtually complete in 24 hours, is in part due to its low viscosity which more readily permits its expectoration and to the speedy absorption and excretion of the iodide.

There has been no evidence of harmful effects from Dionosil, although the number of cases studied is too small to conclude that the medium is entirely innocuous. To date neither pneumonia, pulmonary granuloma, nor iodism have occurred. The fate of the peanut oil in the lungs requires further study, but considerable experience with Iodochlorol, an iodized and chlorinated peanut oil, as a bronchographic medium indicates that this oil is relatively harmless. Tomich, Basil, and Davis,[5] utilizing radioactive tracer techniques, found no free inorganic iodide in the urine after Dionosil bronchography. The contrast medium is excreted entirely as an organic iodide. Iodism has been attributed to the presence of the free iodide ion[14, 15] and, therefore, should probably not occur with Dionosil. The combined experience with resected lung specimens after bronchography with oily Dionosil, which amounts to only 17 cases including the seven in the present series, revealed no apparent gross or microscopic damage to the lung.

The optimal time interval between bronchography and operation has not yet been established for Dionosil, but, judging from present indications, it would appear that a waiting period is not necessary.

Oily Dionosil has all the essential attributes of Lipiodol and water-soluble media without their disadvantages. We feel that this medium, or one similar to it, will ultimately replace those currently used for bronchography.

SUMMARY

Oily Dionosil, a recently developed bronchographic medium, was employed in 30 bronchograms, The results are compared to an equal number of Lipiodol bronchograms, and indicate that oily Dionosil is a safe contrast medium which has all the attributes of Lipiodol and, in addition, presents the advantage of rapid disappearance from the chest roentgenogram.

The assistance of Drs. Lee S. Rosenberg, Herbert Braunstein, Edward A. Gall, Robert C. Kratz, and Fred A. Elkus is gratefully acknowledged.

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EFOCAINE—AN EXPERIMENTAL STUDY OF REPORTED COMPLICATIONS

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EFOCAINE consists of a saturated solution of procaine in a synthetic base.[1] When this solution comes in contact with water, supersaturation occurs, and the procaine crystallizes and precipitates. In clinical use of the drug the tissue fluids initiate crystallization of the procaine; the solvent itself is rapidly absorbed. Theoretically, the procaine crystalline depot thus formed is slowly absorbed, providing local anesthesia until all of the crystals have been absorbed.

Since the introduction of Efocaine a little more than three years ago, several reports have appeared in the literature attributing various complications to its use.[2-8] These include prolonged neuritis, paraplegia, and even death. Further, investigators have reported extensive tissue damage following the use of Efocaine and have indicated that experiments tend to prove that the anesthetic effect induced is secondary to neural necrosis produced by the solvent.[9, 10]

Efocaine has been used in many regions of the body to achieve prolonged local anesthesia, but the authors have used it solely to induce intercostal nerve block.[11-13] Because of the many adverse reports concerning the use of Efocaine, it seemed appropriate to investigate the effects of intercostal injections of Efocaine in the dog, in regard to tissue damage and complications. It has previously been shown that Efocaine will produce a satisfactory intercostal nerve block of approximately 14 days' duration.[11-13]

METHODS

Varying arbitrarily, specified amounts of Efocaine (0.25 c.c., 0.5 c.c., 1 c.c., 2 c.c.) were introduced percutaneously into anesthetized (intravenous Nembutal) dogs to produce intercostal nerve blocks. Five intercostal nerves (6th, 7th, 8th, 9th, and 10th), on one side at a time, were injected with similar amounts of Efocaine 5 cm. from the vertebral spine. The dogs were sacrificed at intervals varying from 5 minutes to 28 days and the sites of the injections studied microscopically. The success of each intercostal block was assured by the absence of scratch reflex to pinprick except when the time interval was so short (5 minutes) that the dog did not recover from the initial anesthetic prior to biopsy. Further, at the time of sacrifice, it was noted in every case that mechanical stimulation of the intercostal nerve distal to the block resulted in muscular contraction. Stimulation of the nerve proximal to the block did not cause muscular contraction, except in those cases wherein the time interval was such that the effect of the Efocaine had been dissipated (greater than 14 days).

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Multiple microscopic sections were prepared from each area of injection. There were 5 specimens for each of the 4 dosages and 7 different intervals, so that in all 140 different sites of injection were studied. In general, the severity of the reaction varied, but not directly so, with the amount of Efocaine injected. The changes noted were as follows:

Five minutes: There were no changes noted in any of the 20 nerves examined.

Twenty-Four Hours: The majority of the nerve sections did not reveal any changes; but a few showed swelling of the myelin sheaths, and two showed minor hemorrhage.

Seventy-Two Hours: General nerve structure was still normal, but vacuolization, swelling and basophillic staining were present.

Seven Days: All nerves showed severe destruction as evidenced by focal hemorrhage, vacuolization, partial absence of fibers, nuclear fragmentation, and disruption of nerve sheaths.

Fourteen Days: Same changes were present as for seven days except that in a few sections perineural fibrosis was beginning to occur.

Twenty-One Days: Severe destruction was still present as evidenced by complete lack of organization of the nerves. Nerve fibers were not identifiable as such; much vacuolization was present; some few capillaries were noted in the nerve bundles (Fig. 1).

Twenty-Eight Days: Nerves were recognizable, although edema was still present. Many sections showed small nerve tract formation and myelin axon regeneration.

The effect of Efocaine on muscle, artery, vein, subcutaneous tissue, fat, pleura, and periosteum was also noted. The muscle tissues were usually fragmented, hemorrhagic, and infiltrated with phagocytes. The reaction was always more severe in the muscle than in the nerve. The arteries and veins frequently showed endothelial proliferation and/or thrombosis, particularly when the larger doses were used. The other contiguous tissues showed little or no reaction.

COMMENTS

It was immediately apparent that the anatomical changes produced by Efocaine were more pronounced than the physiologic changes. At 21 days, for example, even though the nerves appeared to be completely disrupted, each one had regained its function as judged by ability to transmit both afferent and efferent impulses. Nevertheless, the reaction produced is severe, and prolonged neuritis theoretically might well occur following such a severe chemical reaction.

Paraplegia did not occur in any animal receiving an intercostal nerve block with Efocaine. Yet it has been reported several times as following intercostal block in human beings. Explanations so far for the development of such paraplegia have been based on the assumption either (1) that Efocaine reaches the spinal cord by capillary action along the nerve fibers themselves or (2) that Efocaine was actually injected into a perineural dural extension. While the former may have some basis, as shown experimentally by Moore,[7] the latter does not, for introduction of Efocaine into the subarachnoid space itself produces

only a prolonged spinal anesthesia (10 to 14 days). Batson's work,[14] which demonstrated the collateral circulation between the intercostal and spinal veins, suggested an inquiry into the possible effect of the introduction of Efocaine into the intercostal vessels. It is easy to understand how intravascular injection may occur during initiation of an intercostal nerve block, with the vessels being in such close proximity to the nerve. Also, it is well known that lack of aspiration of blood through a needle does not guarantee that the tip of the needle is not in a vessel. As a preliminary experiment 3 c.c. of Efocaine were introduced into an anesthetized dog's exposed right fifth intercostal artery and into another

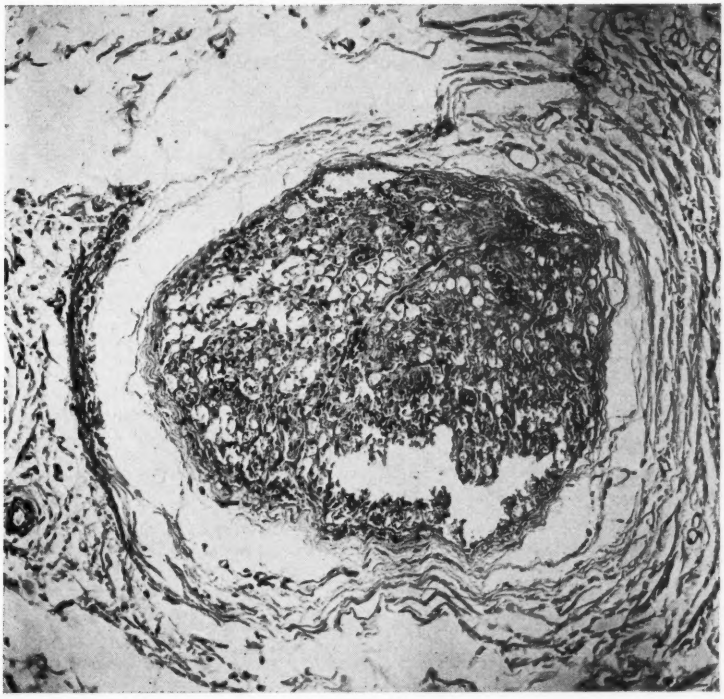

Fig. 1.—Section of intercostal nerve twenty-one days after initiation of intercostal nerve block with Efocaine. The uniform nerve structure is lost; there are foci of vacuolization and other foci that are more compact than normal. The former represent distended myelin sheaths; the latter represent proliferation of neurilemma cells. There is a slight infiltration of lymphocytes. The irregular cleft is an artefact. The changes in the nerve are similar to those that occur in wallerian degeneration. (×75.)

dog's corresponding vein. Both dogs became paraplegic immediately and expired in about a week. Microscopic sections of the spinal cords showed severe destruction of the cords and thromboses of the vessels of the cords. Thus, the explanation for the paraplegia seemingly became apparent—intercostal intravascular injection of Efocaine produces paraplegia. In order to test this theory, an experiment was devised wherein 1 c.c. aliquots of Efocaine were introduced under sterile precautions into the surgically exposed fifth intercostal artery, or vein, of several dogs and the cords removed and studied at varying intervals.

RESULTS

It was noted that successful injection into either the intercostal vein or artery was acompanied by extreme fasciculation of the muscles on the injected side below the level of injection. Thus, it was possible to know that all injections were successful. Fourteen dogs were injected; seven in the artery, seven in the vein. At intervals varying from 10 minutes (time required to expose the cord after the injection) to 5 weeks, the spinal cord was removed and microscopic sections made of the involved area.

Paralysis was present to some degree in 12 of the 14 dogs so injected. In some cases both hind legs were partially affected, in others paraplegia was present. In two dogs only the limb on the injected side was involved; two other dogs did not show any involvement. The duration and severity of the paralysis varied, but in every animal that was to show improvement, it became evident by the third day.

A brief summary of the lesions present in each dog is presented in Table I.

TABLE I. SUMMARY OF EXPERIMENTS—INTRAVASCULAR INJECTION OF EFOCAINE

I. *Intercostal Arterial Injections:*

Dog No. 1513 was sacrificed immediately while still anesthetized. There was no cord, vascular, or meningeal lesion.

Dog No. 1517, sacrificed at 24 hours, had paralysis of the left hind leg, edema of central area of cord, but no vascular or meningeal reaction.

Dog No. 1518, sacrificed at 24 hours, was paraplegic, had necrosis and hemorrhage of almost the entire cross section of the cord, necrotizing and exudative thromboangiitis, and the meninges showed acute inflammatory changes.

Dog No. 1512, sacrificed at 4 days, was paraplegic; there were necrosis and hemorrhage in the left anterolateral section of the cord. The vessels showed a necrotizing thromboangiitis, and the meninges presented acute inflammation and proliferation (Fig. 2).

Dog No. 1509, sacrificed at 7 days, had bilateral partial paralysis, with it being more marked on the left. Microscopic sections showed cystic necrosis of the posterior half of the cord, exudative and proliferative angiitis of the vessels, and chronic inflammation of the meninges.

Dog No. 1515, sacrificed at 7 days, also had bilateral partial paralysis, more marked on the left. Microscopic sections revealed necrosis and hemorrhage of the posterior central part of the cord, slight exudative angiitis of the vessels, and no meningeal reaction.

Dog No. 1502, sacrificed at 35 days, had bilateral partial paralysis, with more involvement on the left. Microscopic sections revealed cystic necrosis of the central part of the cord, proliferative arteritis of the vessels, and hemosiderosis and chronic inflammatory changes in the meninges.

II. *Intravenous Injections:*

Dog No. 1514 was sacrificed without recovery from anesthetic. Microscopic sections did not reveal any lesions of the cord, vessels, or meninges.

Dog No. 1510, sacrificed at 24 hours, was paraplegic. Microscopic sections revealed necrosis and hemorrhage of the left half of the cord, necrotizing thromboangiitis of the vessels, and acute inflammation of the meninges.

Dog No. 1511, sacrificed at 24 hours, was paraplegic. Microscopic sections presented necrosis and hemorrhage of practically the entire cross section of the cord, necrotizing thromboangiitis of the vessels, and hemorrhage and inflammatory changes in the meninges.

Dog No. 1508, sacrificed at 4 days, was paraplegic. Microscopic sections revealed necrosis and hemorrhage of the anterior central portion of the cord, necrotizing thromboangiitis of the vessels, and hemorrhage with moderately acute inflammatory changes in the meninges.

Dogs Nos. 1519 and 1520, sacrificed at 7 days, had no signs, nor was any lesion of the cords found at autopsy. (Each dog presented signs of a successful injection at the time of injection, but was never paralyzed.)

Dog No. 1501, sacrificed at 35 days, had bilateral partial paralysis, more marked on the left. Sections revealed cystic necrosis of the right posterocentral portion of the cord, with no involvement of the vessels or meninges (Fig. 3).

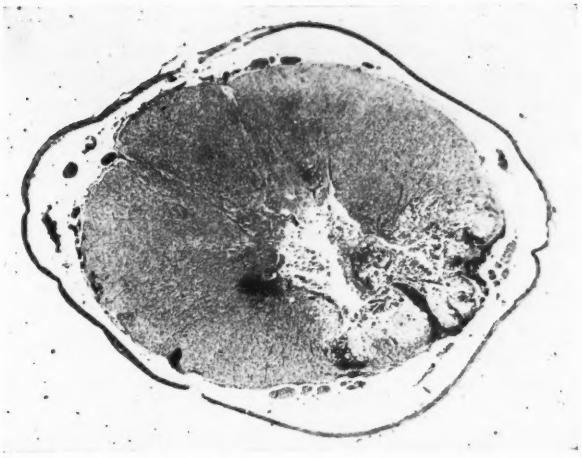

Fig. 2.—Section of spinal cord of Dog No. 1512 ninety-six hours after injection of 1 c.c. of Efocaine in the intercostal artery. There is a focus of necrosis and hemorrhage involving most of the central and anterolateral portions. A cavity has commenced to form. A lesser degree of degeneration is present in the posterior and lateral parts of the cord on the same side. (×8.)

Fig. 3.—Section of spinal cord of Dog No. 1501 thirty-five days after injection of 1 c.c. of Efocaine in the intercostal vein. The posterior and lateral portions of the cord are replaced by an area of cystic necrosis. Only a few strands of glial and vascular connective tissue are present in this focus. (×8.)

SUMMARY

Efocaine, when used to induce an intercostal block in the dog, produces necrosis of the nerve and the contiguous tissues. This reaction is more severe anatomically than physiologically. The injection of Efocaine into an intercostal vessel produces myelitis of a varying unforecastable degree. Whether this effect is produced by chemical necrosis of the cord or by chemical thrombosis of the cord blood vessels was not determined.

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